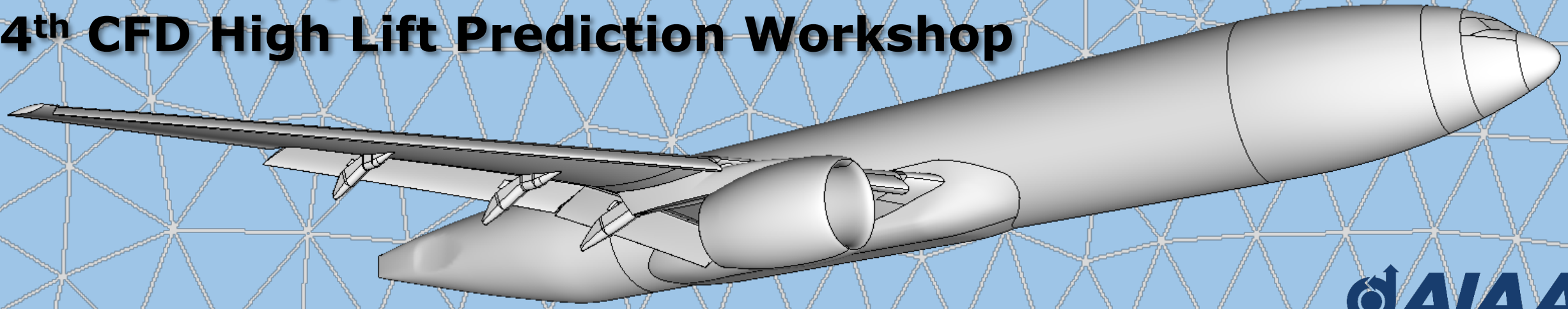
3rd Geometry and Mesh Generation Workshop
4th CFD High Lift Prediction Workshop



AIAA
SHAPING THE FUTURE OF AEROSPACE

Fixed-Grid RANS TFG

Carl Ollivier-Gooch (University of British Columbia)
Jim Coder (University of Tennessee, Knoxville)

Team Details, Fixed-Grid RANS

TFG ID/Name
G = Geometry
R = RANS
A = Adaptation
H = High-order
L = Hybrid RANS/LES
W = WMLES/LB

Partic. [# datasets]	Tools Used (Grid/Solver/Turb Model)	Test Cases				
		1a	1b	2a	2b	3
R-004 [5]	PW, Custom / TAS / SA, SA-noft2-R	4	4	x		x
R-008 [6]	PW / FUN3D / SA, SA-QCR2000	2	1	5		x
R-009 [5]	ANSA, Custom / scFLOW / SA-neg	x	1	4		
R-011 [2]	PW / HiFUN / SA	x	1	2		x
R-015 [4]	PW / USM3D / SA-neg	1	1	4		x
R-019 [15]	PW / CFD++ / SA-*	1	1	15		x
R-021 [3]	ANSA, Custom / zCFD / SA-neg, SST-V	2	1			x
R-025 [13]	SMB / LAVA / SA-*	8	8	13		x
R-028 [4]	Custom / NSMB / SA-*	2		4		

Partic. [# datasets]	Tools Used (Grid/Solver/Turb Model)	Test Cases				
		1a	1b	2a	2b	3
R-032 [1]	PW / ACTFlow, SA-noft2	x	1	1		x
R-034 [9]	PW / CHAMPS / SA	1	1	7		x
R-037 [9]	SMB / OVERFLOW / SA-*	8	8	3		
R-043 [12]	PW / TAU / SA-neg, SST, RSM	9	x	9		x
R-050 [1]	PW / TAU / SA-neg	1		1		x
R-054 [3]	PW / Fluent / SA, SST			3		x
R-057 [6]	PW, ANSA / Cflow / SA-neg	2	1	2		x
R-059 [9]	PW, Custom / STAR-CCM+ / SA, SST, ke-lag-EB			9		x
R-060 [10]	PW, ANSA / Flow360 / SA-neg	2	5	8		x

Key Questions

#	Key Question	Addressed By Which Groups (GID)	Adequately answered with supporting evidence?
1	What are the meshing resolution requirements and best practices/guidelines for different regions of the lift curve?	All but R-028	Partial
2	Can RANS modeling accurately predict the influence of component movement at moderate angles of attack?	R-004, R-008, R-015, R-019, R-021, R-025, R-037, R-050, R-057, R-060	Yes
3	Can RANS modelling accurately predict CL,max?	…	Yes
4	How much error and uncertainty is associated with underconvergence of the solution residual?	…	Partial
5	What is the effect of solution strategy (e.g. global CFL condition, global time stepping, quasi-Newton, initial conditions, etc.) on the predictions?	R-019, R-025, R-034, R-037, R-043, R-060	Yes

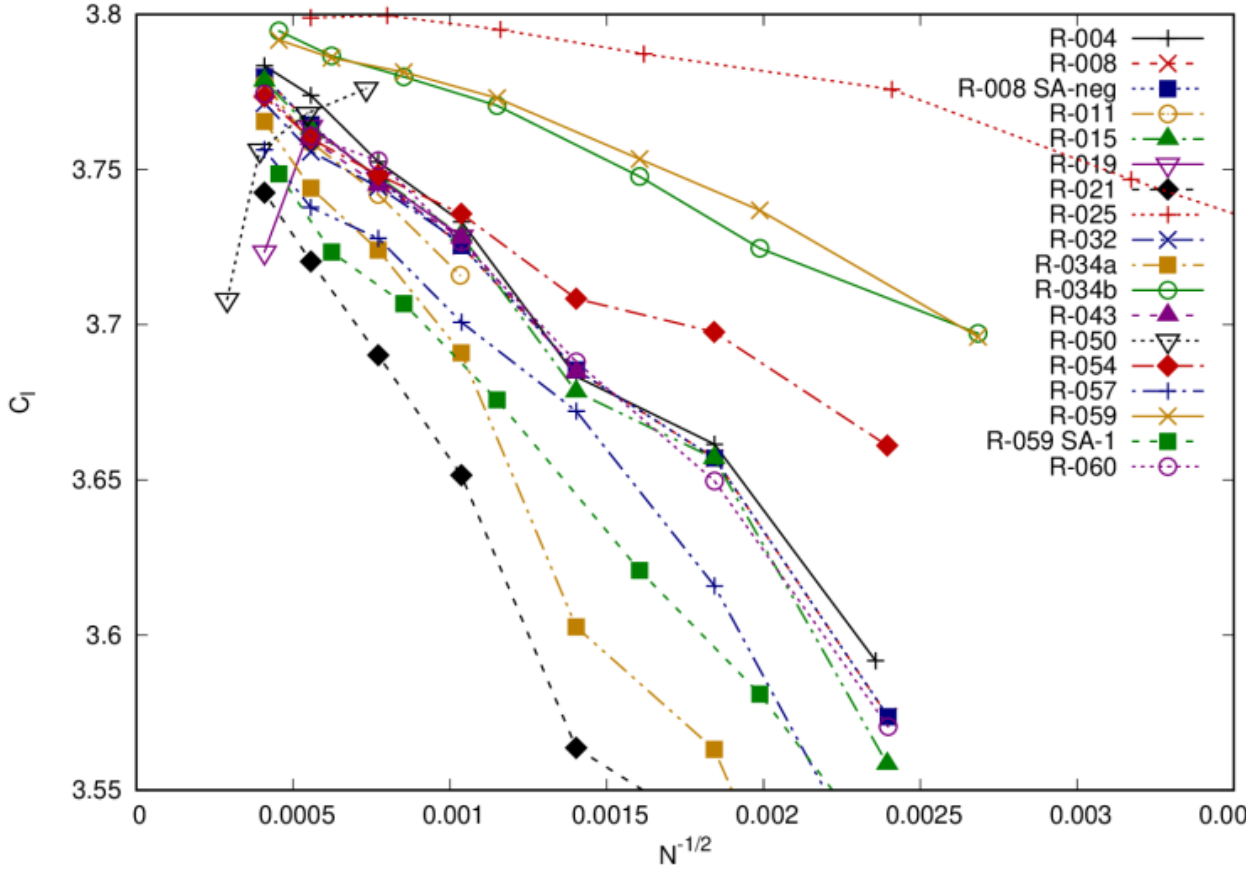
Key Findings / Lessons Learned

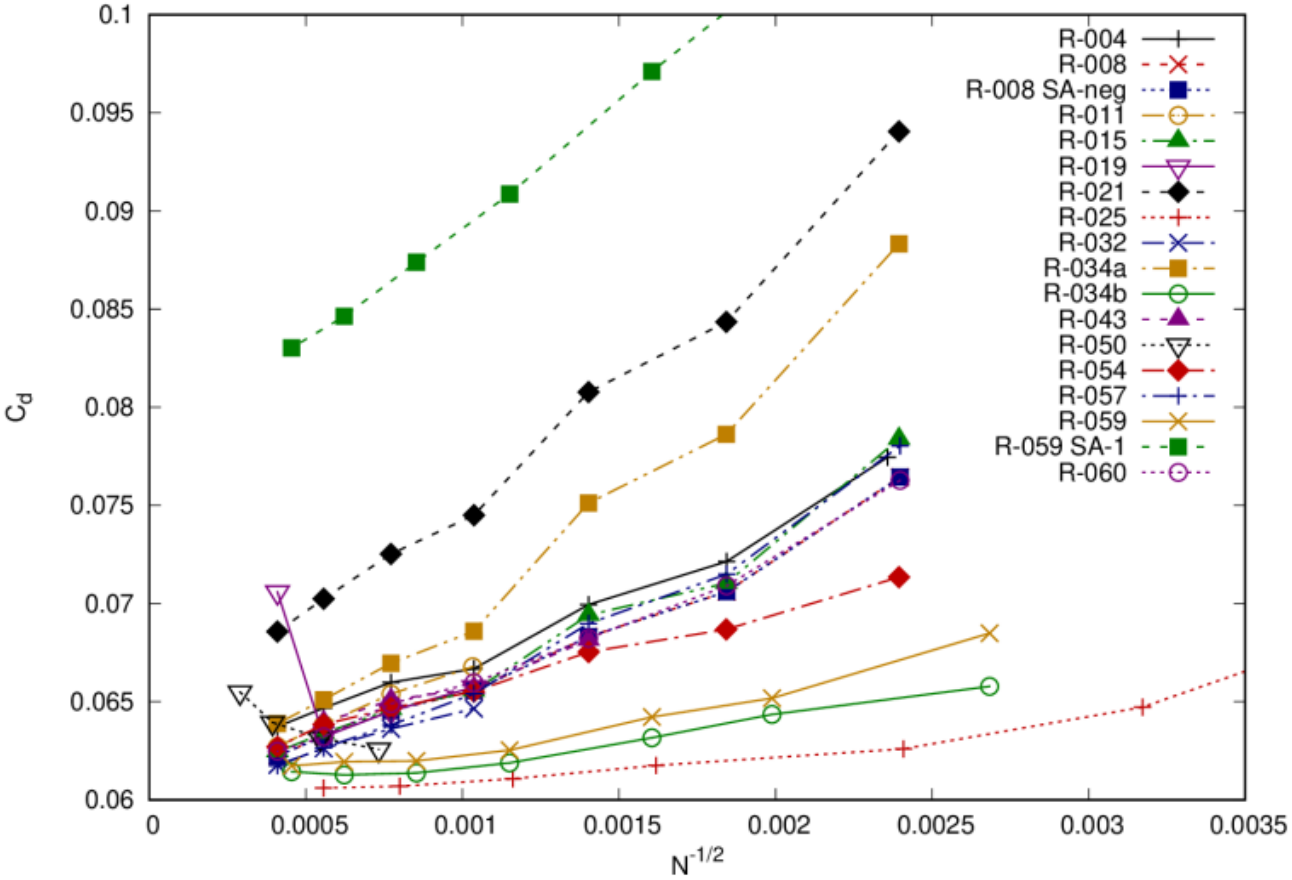
KQ 1	What are the meshing resolution requirements and best practices/guidelines for different regions of the lift curve?

Key Findings / Lessons Learned

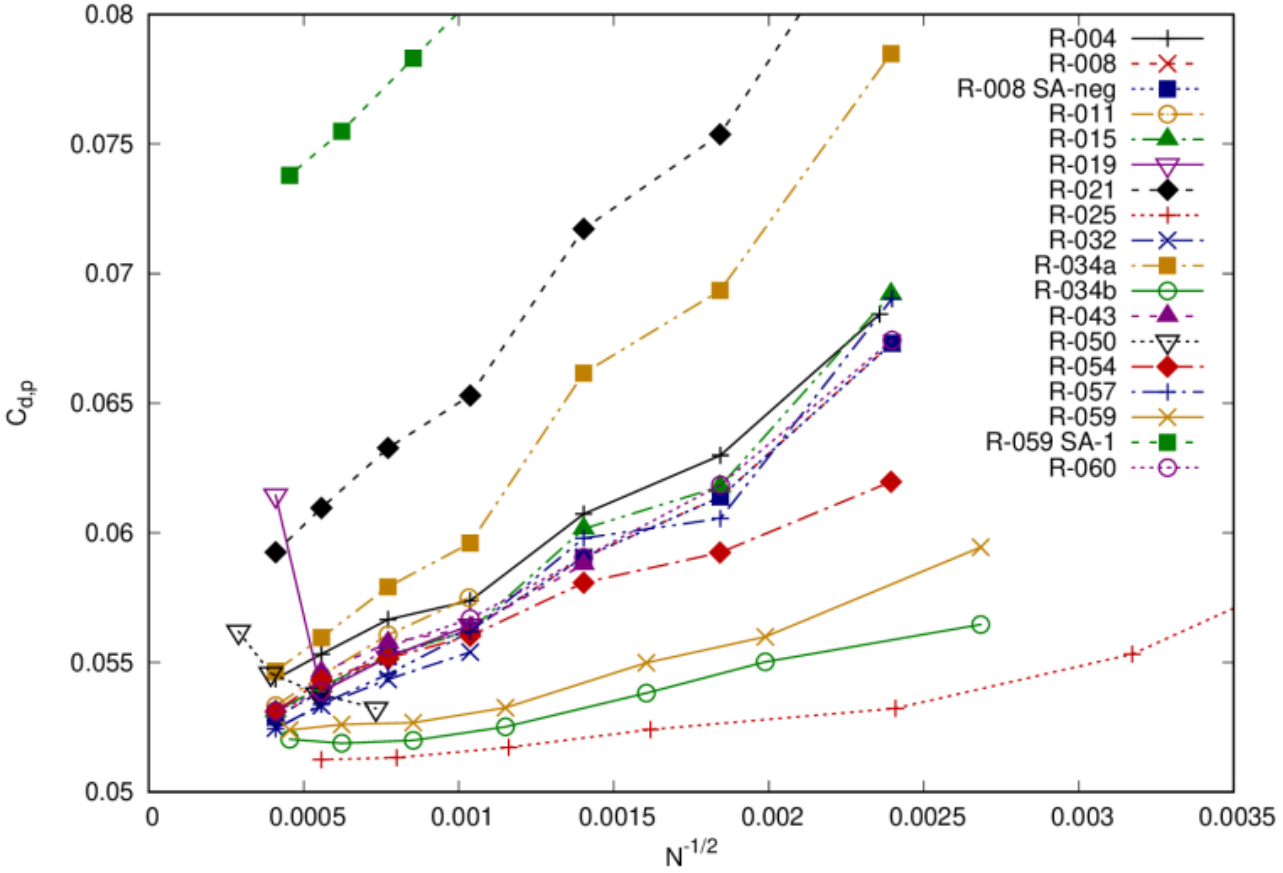
- Grid convergence, even for a single mesh family and turbulence model, is still not good.
- Variations between codes is relatively large across the range of angles of attack.
- D level meshes appear to be sufficient away from stall.
- Near stall, issues of grid convergence, iterative convergence, solution history, and model inadequacy compound, making it impossible to draw conclusions about mesh suitability.

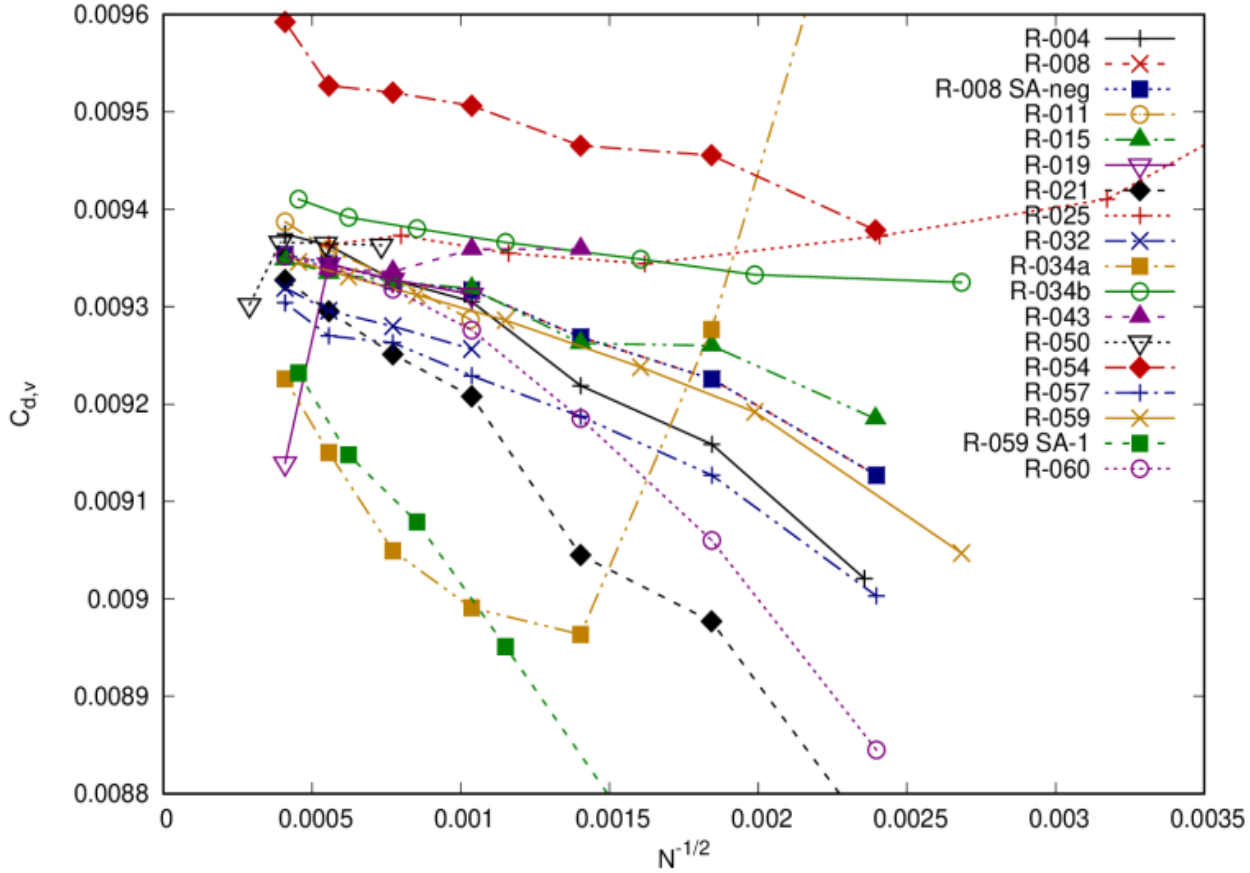
2D Verification Results



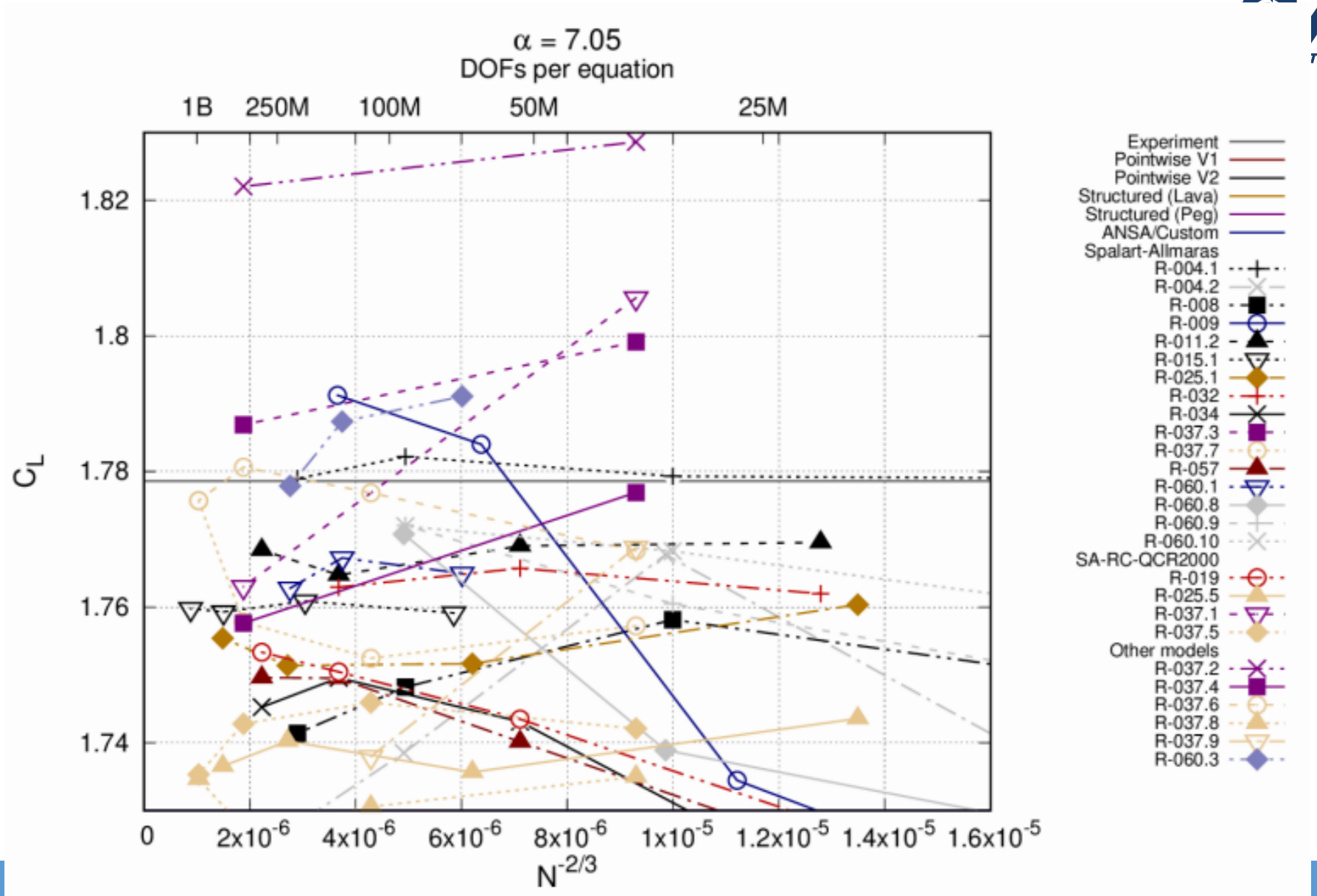


2D Verification Results

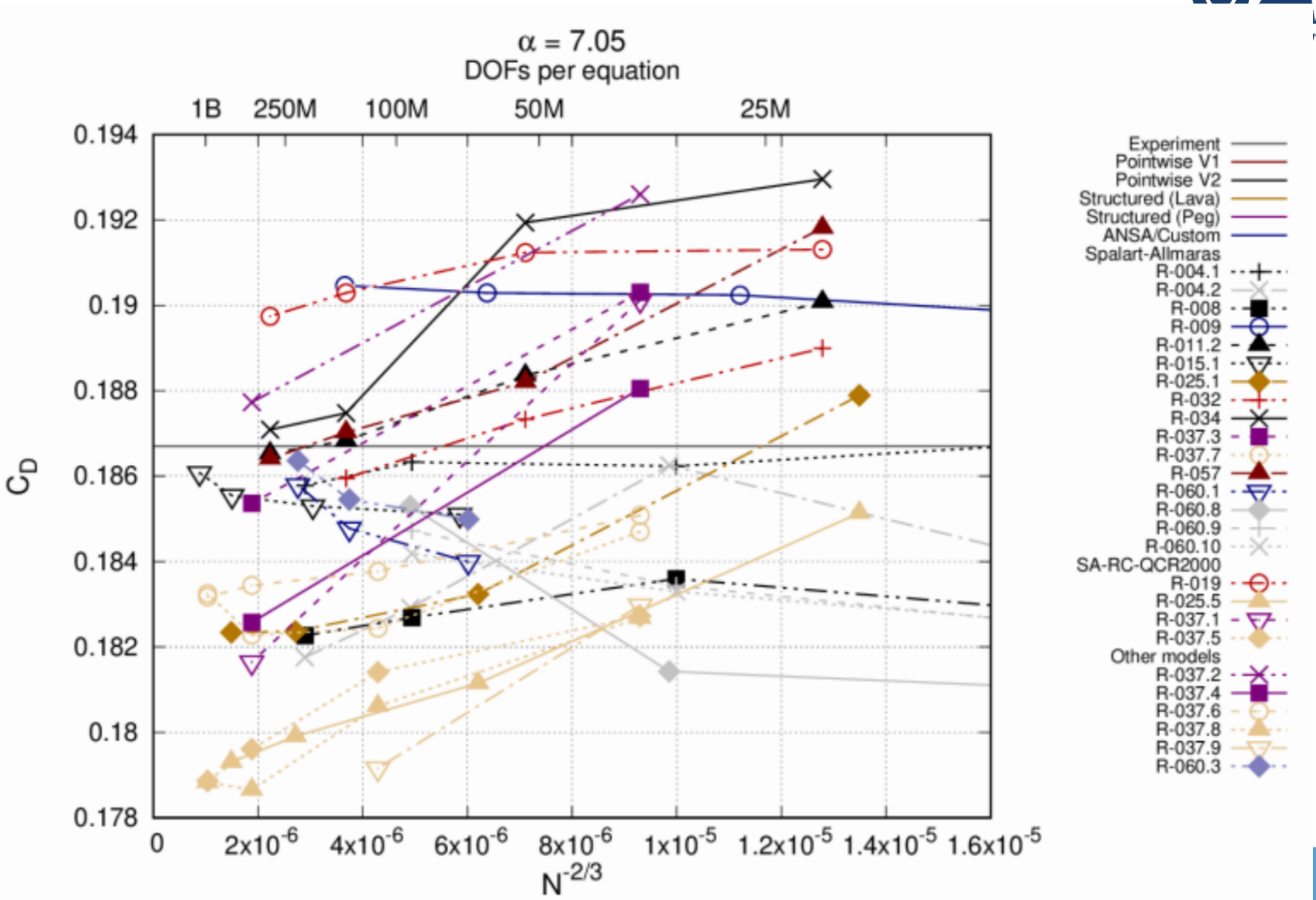




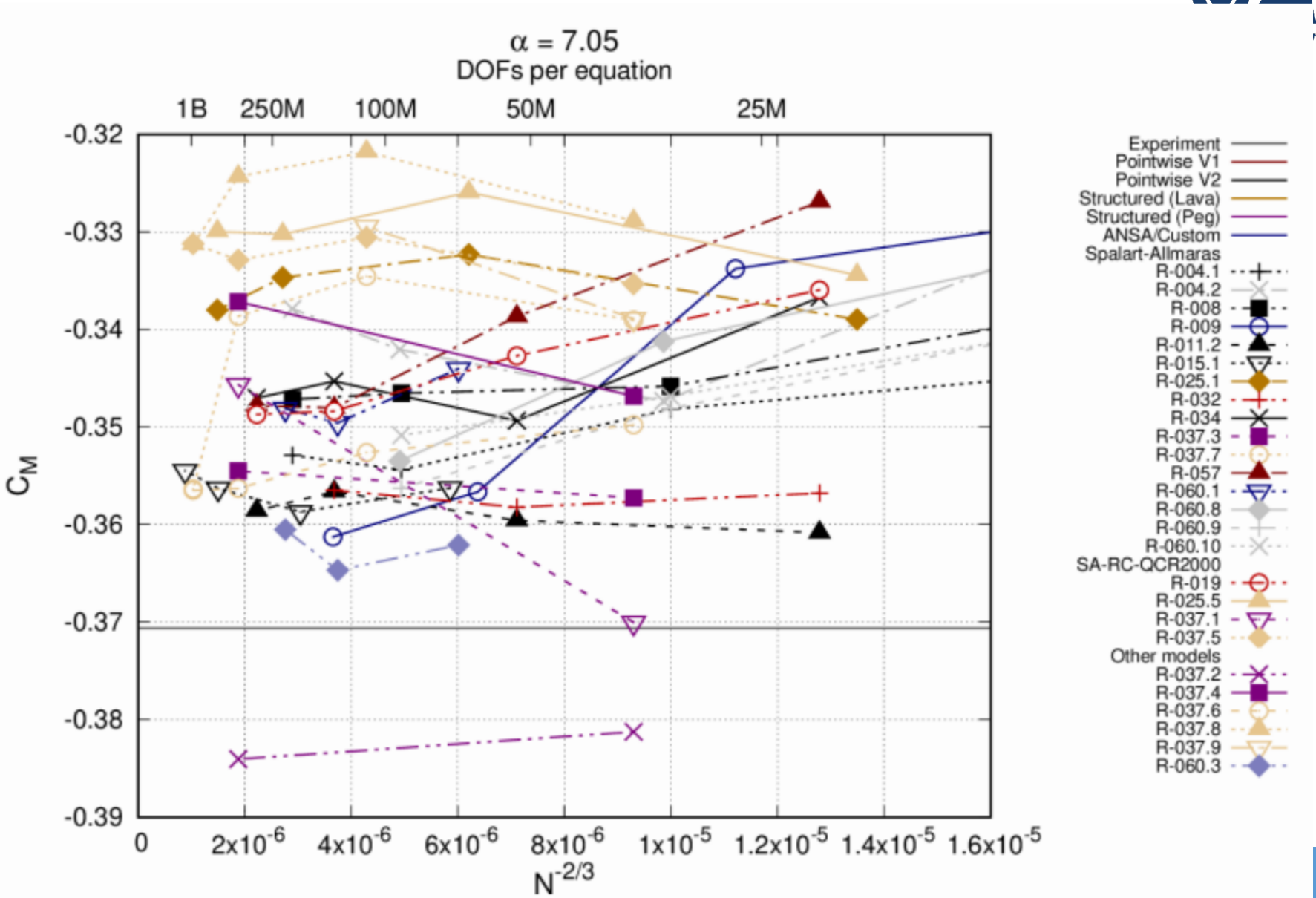
3D Verification Results: AOA = 7.05 degrees



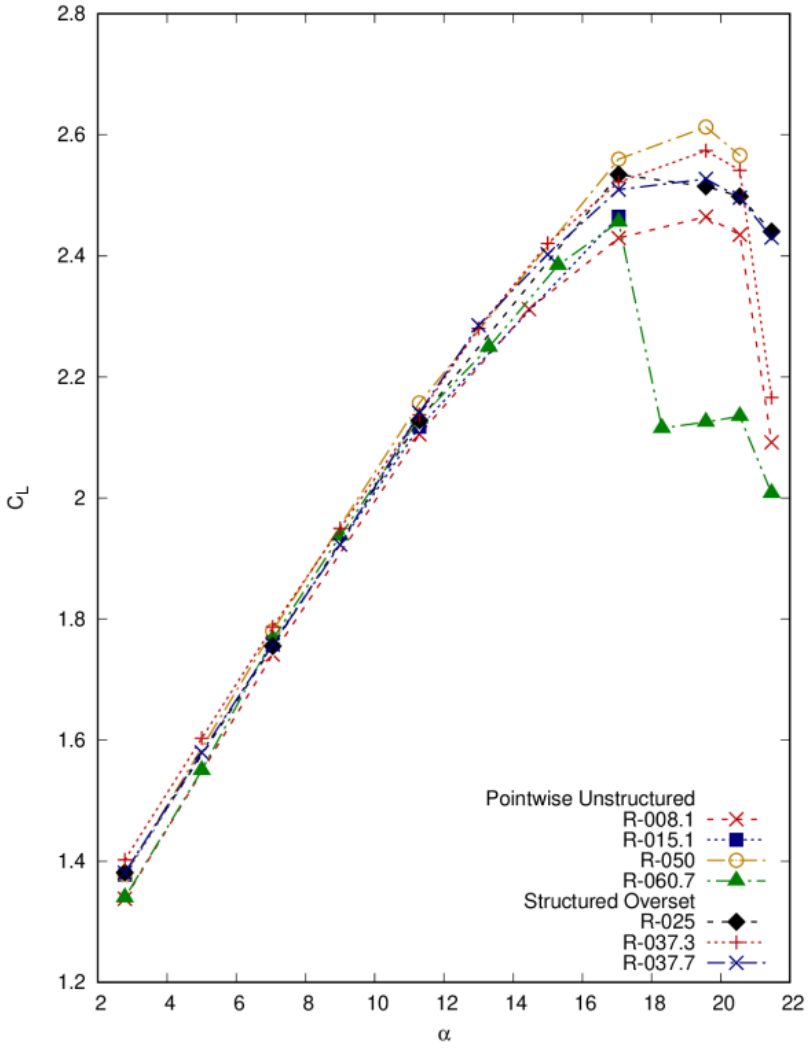
3D Verification Results: AOA = 7.05 degrees

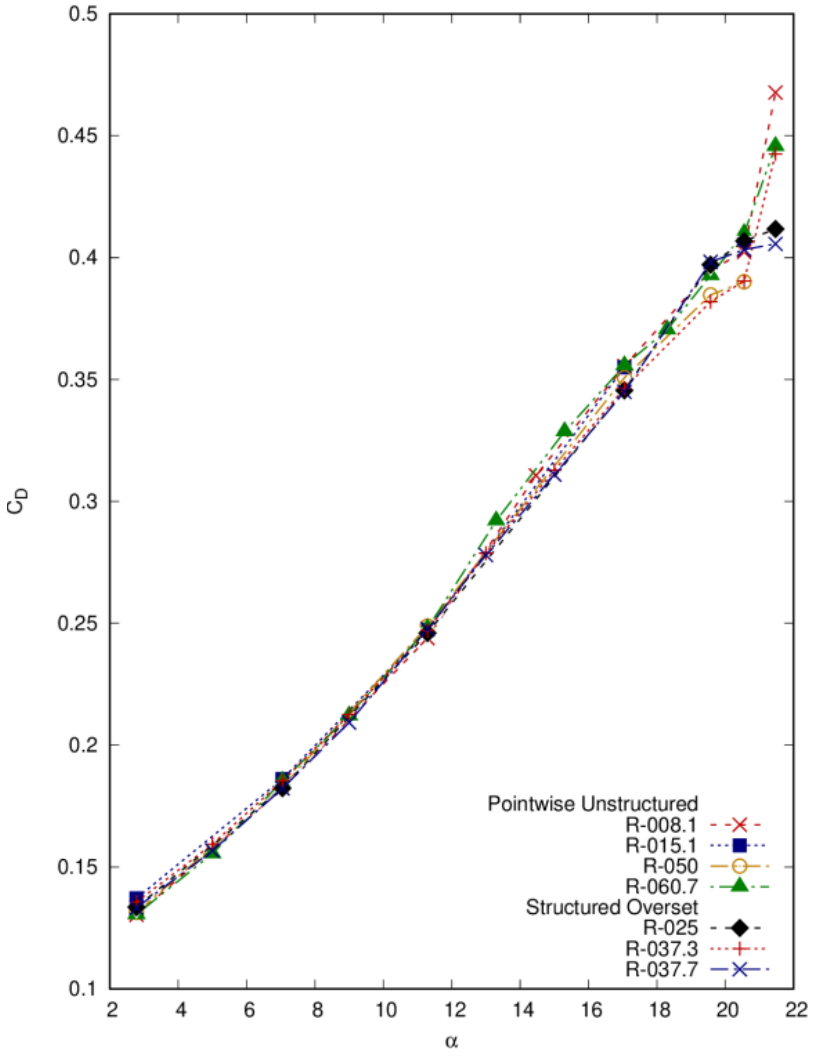


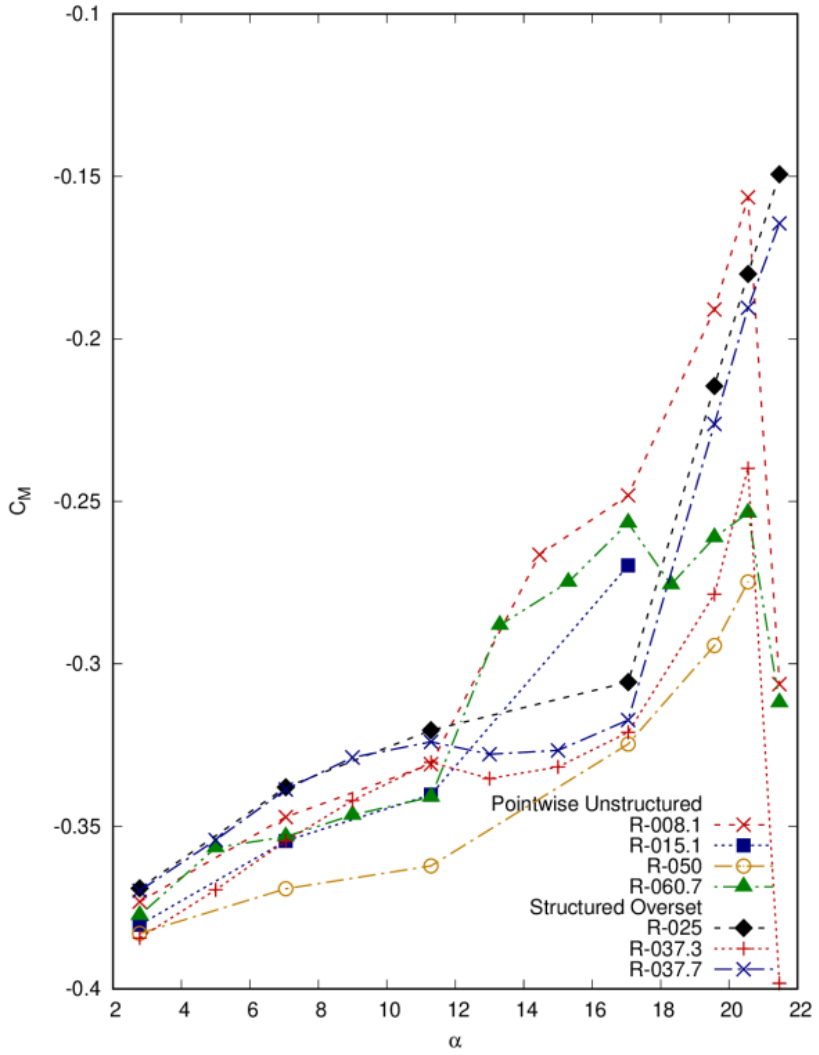
3D Verification Results: AOA = 7.05 degrees



D-mesh Results, Spalart-Allmaras model







Key Findings / Lessons Learned

KQ 2	Can RANS modeling accurately predict the influence of component movement at moderate angles of attack?

Key Findings / Lessons Learned

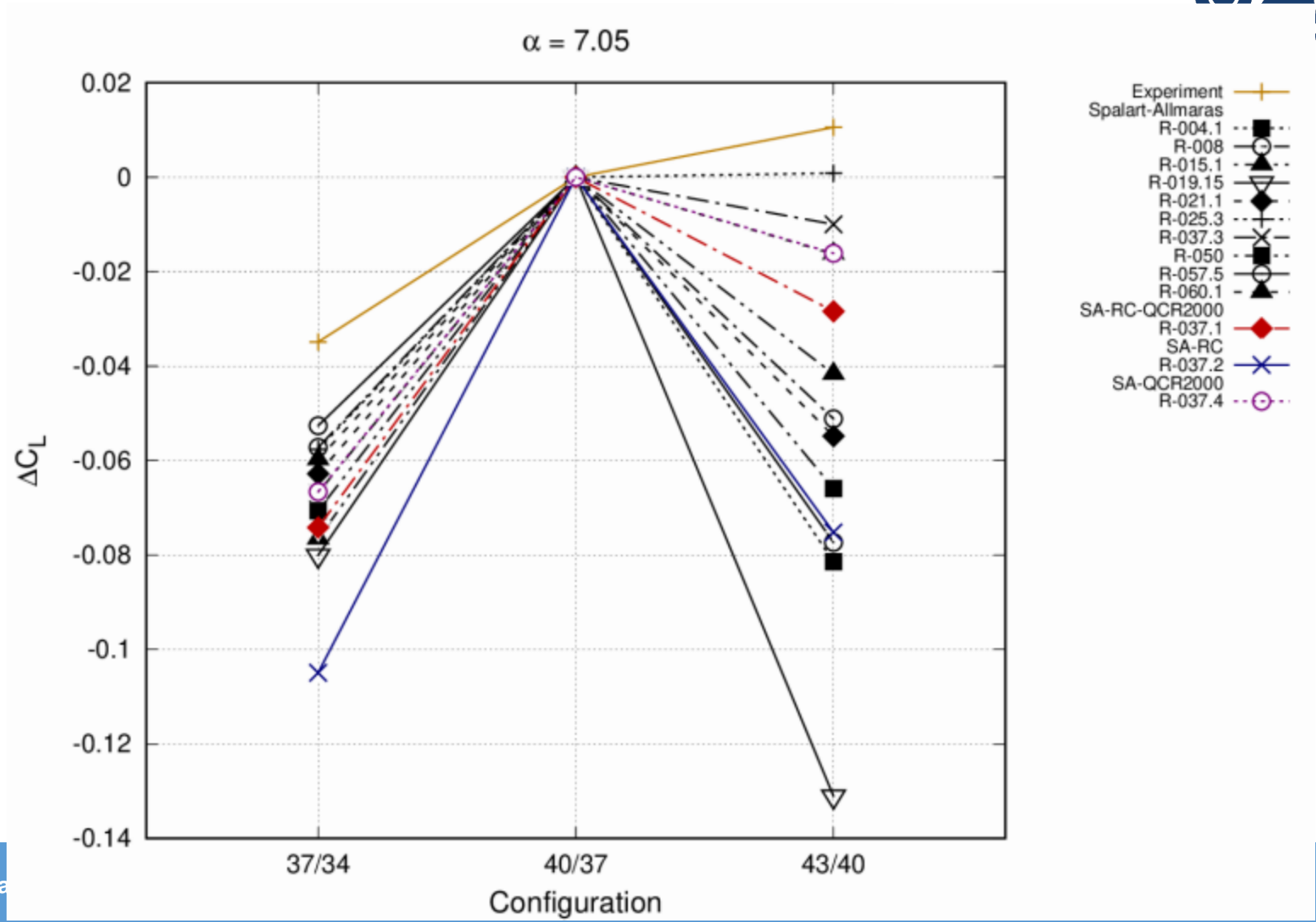
- Lift and moment increments for best-practice results are not consistent with experimental data.
- Average drag increments for best-practice results are consistent with experimental data, but scatter is large.
- Overall, submitted data supports only the conclusion that fixed-grid RANS simulations, as currently deployed in practice, can not accurately predict changes in aerodynamic coefficients, even well away from stall.

Key Question 2

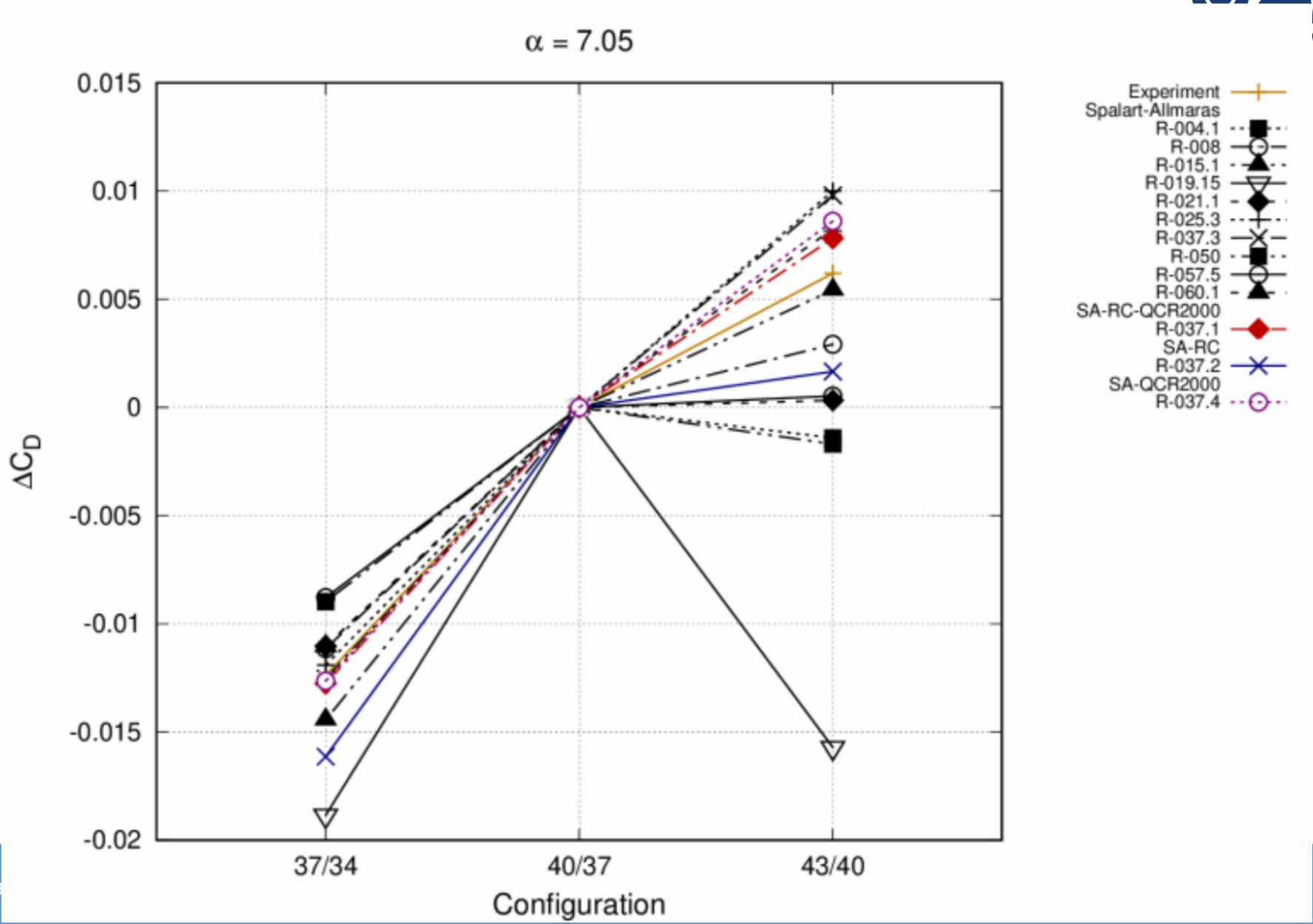
Can RANS modeling accurately predict the influence of component movement at moderate angles of attack?

From 40 deg	To 37 degrees			To 43 degrees		
	Exp	Mean computed	Std dev computed	Exp	Mean computed	Std dev computed
ΔC_L	-0.03488	-0.06915	0.01404	0.01057	-0.04988	0.03677
ΔC_D	-0.01238	-0.01252	0.00286	0.00620	0.00281	0.00701
ΔC_M	0.00441	0.02152	0.01036	0.00018	0.02708	0.01255

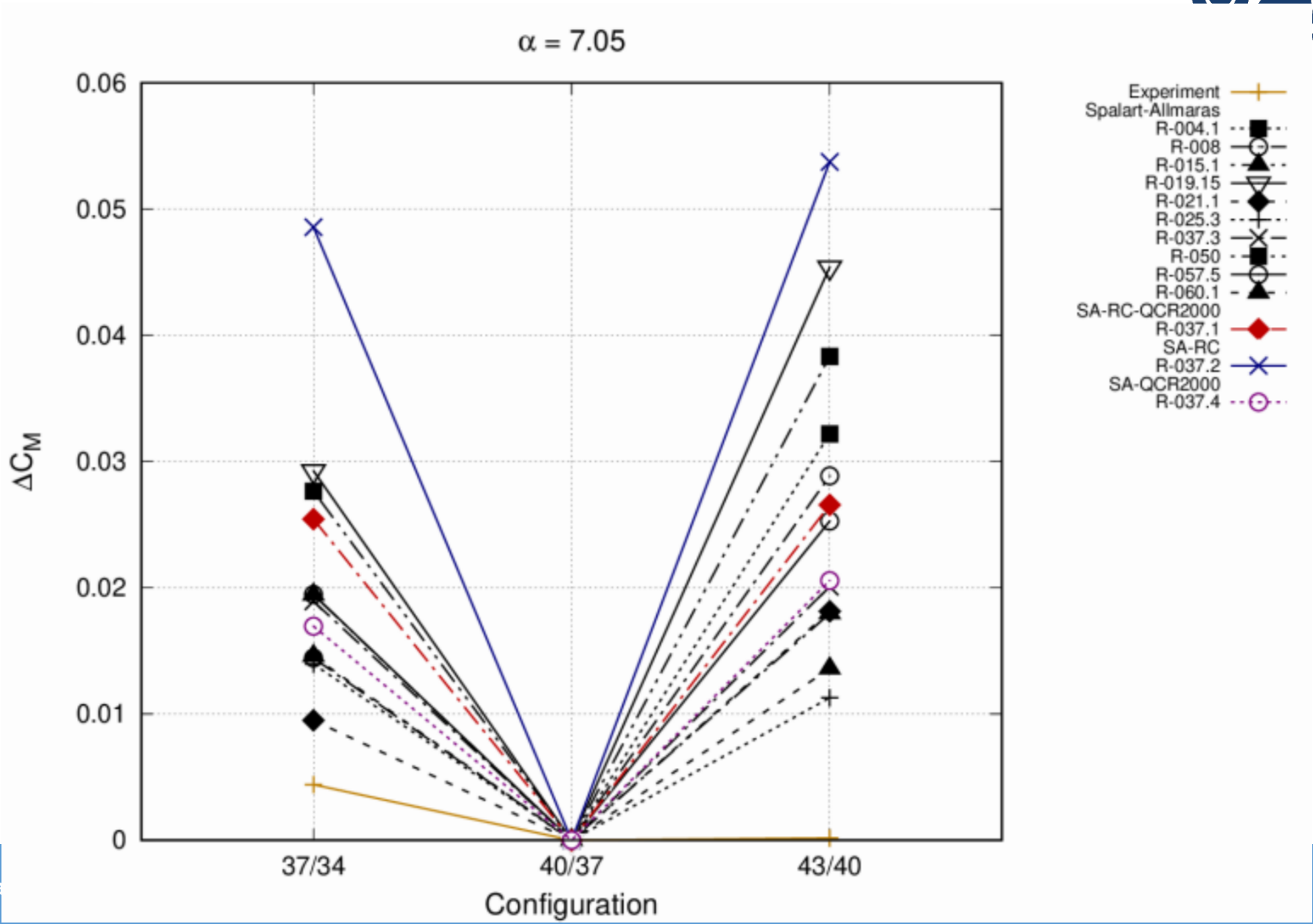
KQ2 / Case 1a: Lift Increments



KQ2 / Case 1a: Drag Increments



KQ2 / Case 1a: Moment Increments



Key Findings / Lessons Learned

KQ 3	Can RANS modeling accurately predict CL,max?

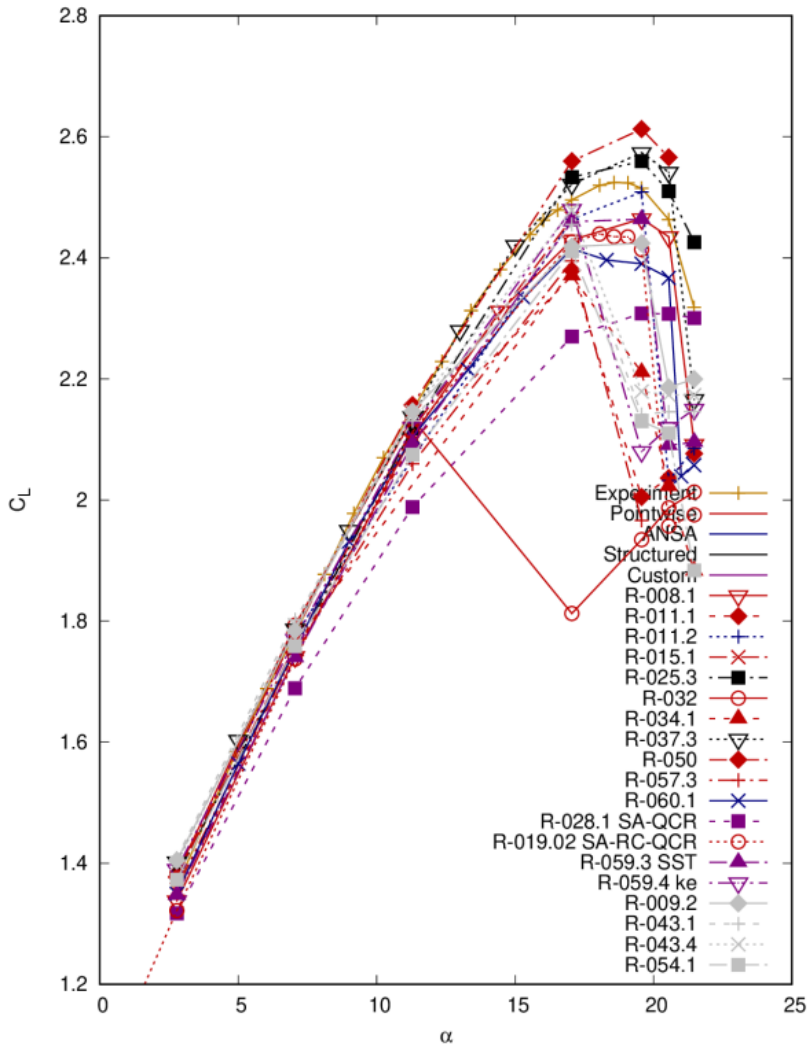
Key Findings / Lessons Learned

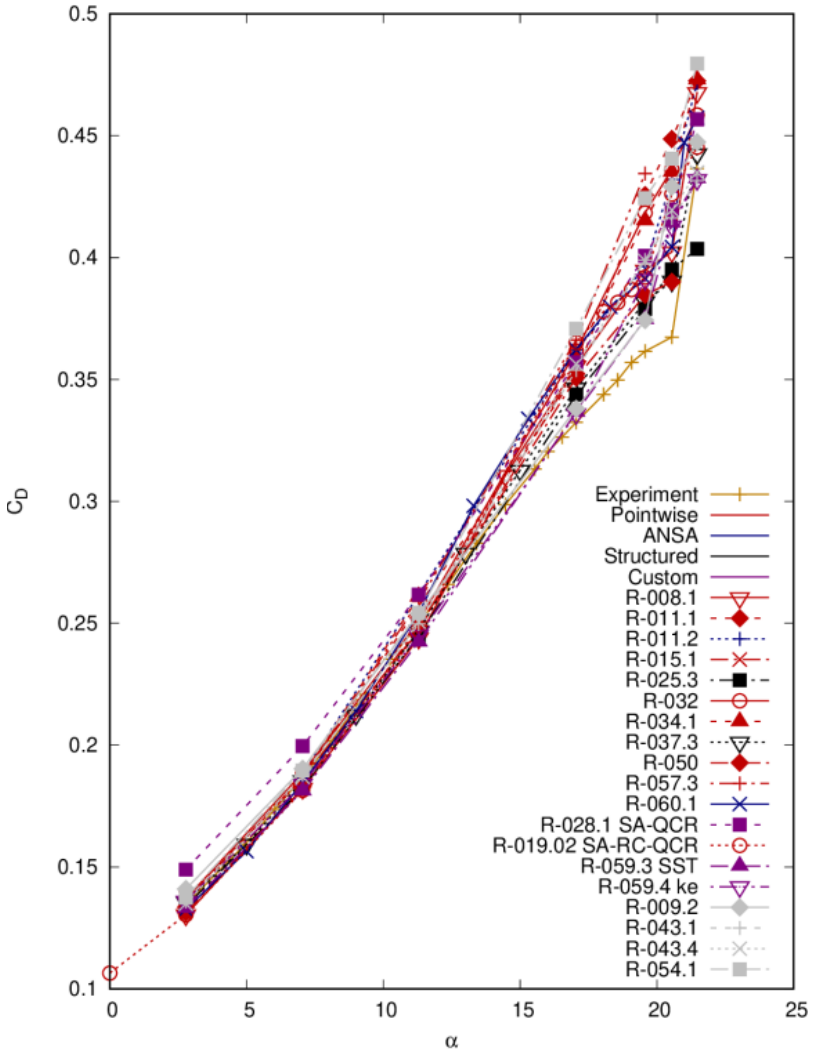
- Lift: several best-practice results are qualitatively in agreement, and not far off quantitatively. About an equal number have a large drop in lift around stall; low lift branch?
- Drag: trends are generally okay, but quantitatively too large.
- Moment: Poorly predicted quantitatively. Several results have no pitch break at stall.

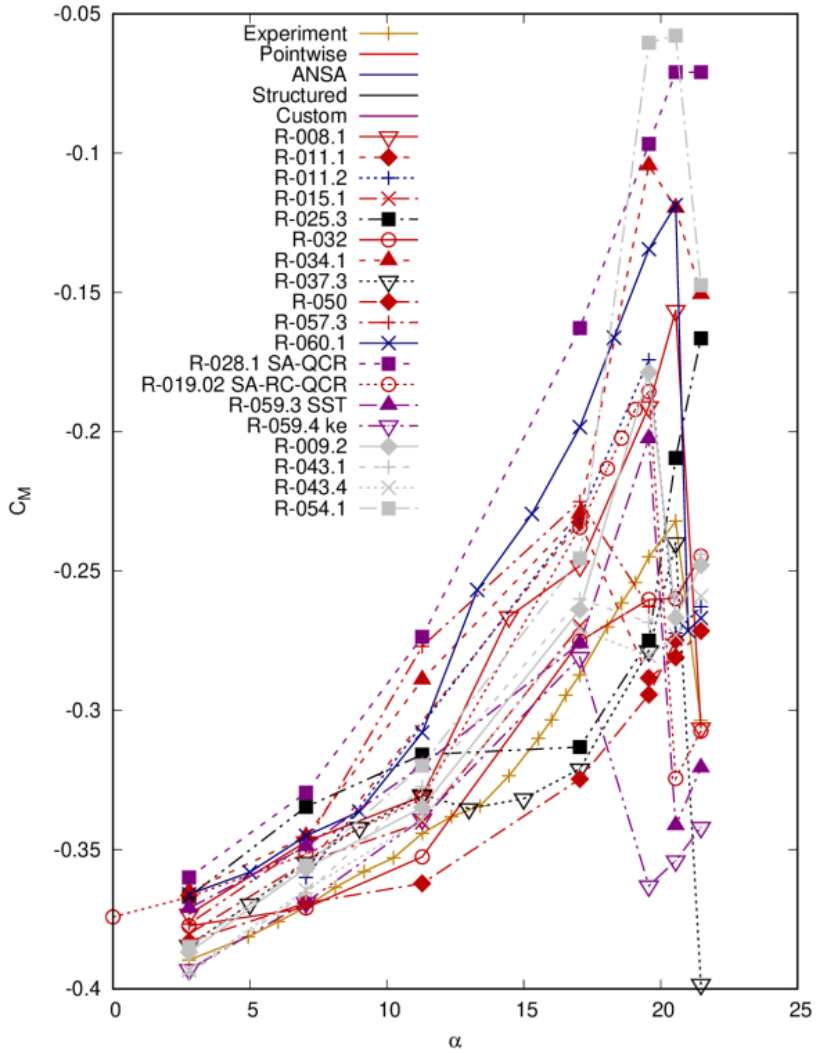
Most data is for Spalart-Allmaras; no possible conclusions about effect of model.

Overall, submitted data supports only the conclusion that fixed-grid RANS simulations, as currently deployed in practice, can not accurately predict aerodynamic behavior near stall.

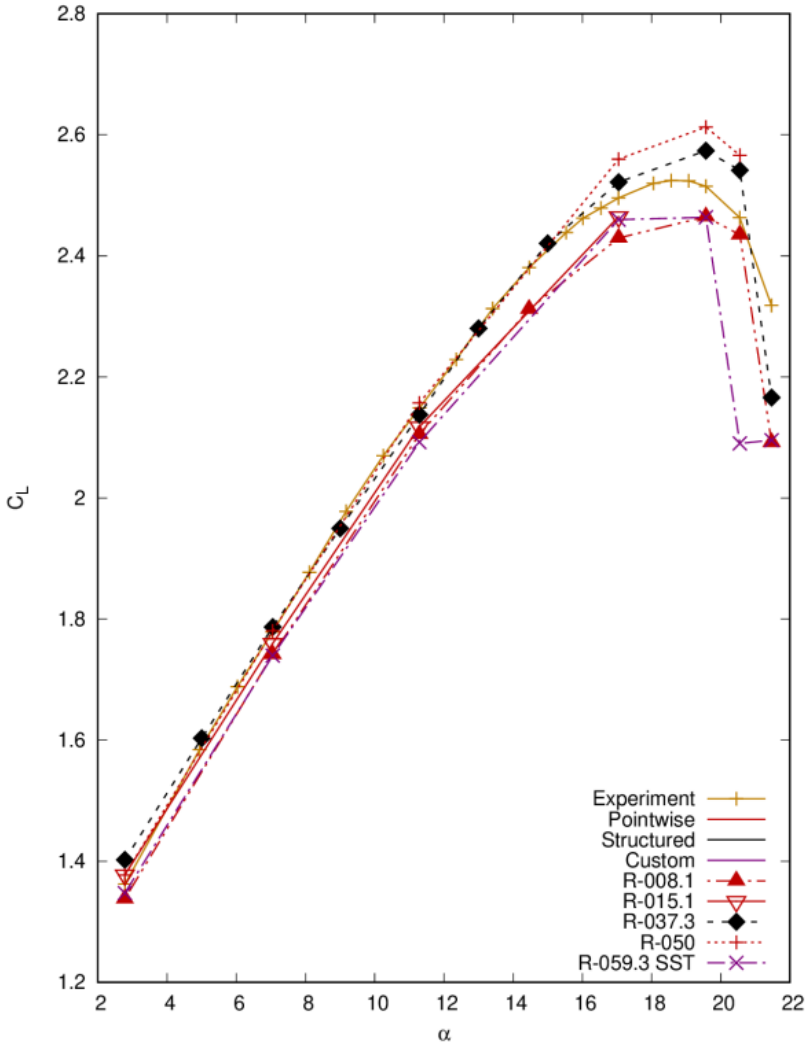
All Best-Practice Results

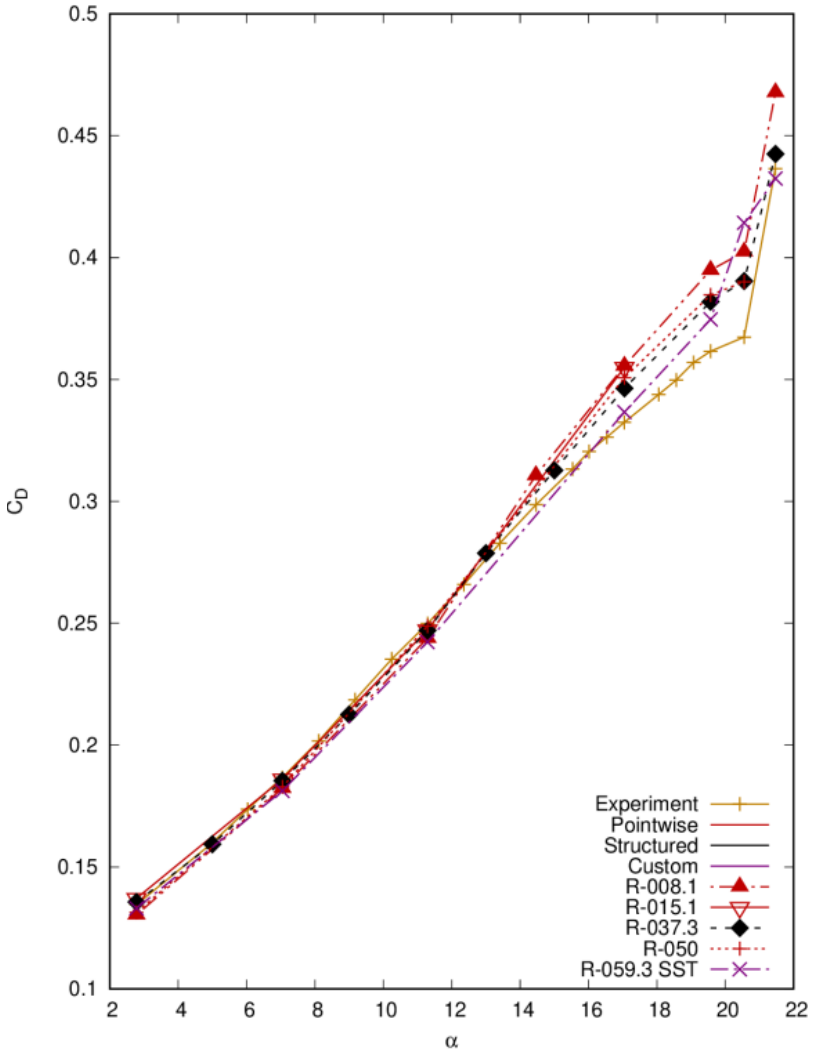


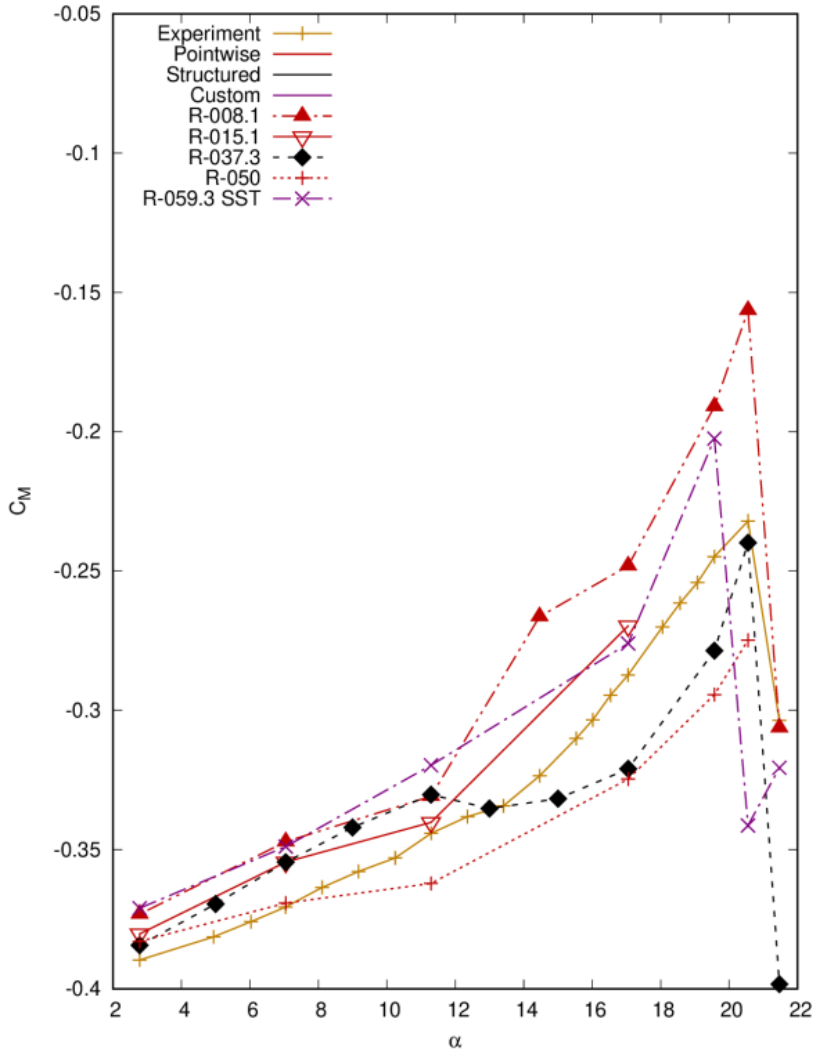




Selected Best-Practice Results







Key Findings / Lessons Learned

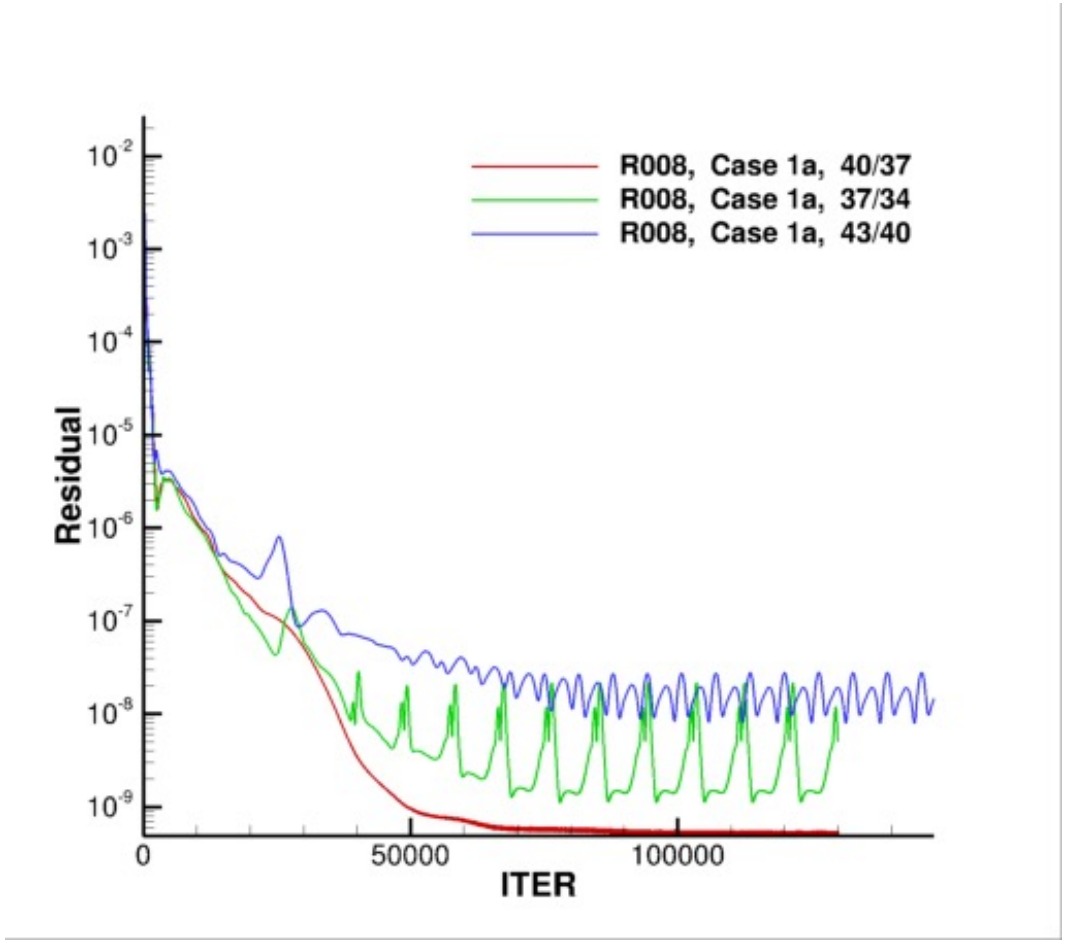
KQ 4	How much error and uncertainty is associated with underconvergence of the solution residual?

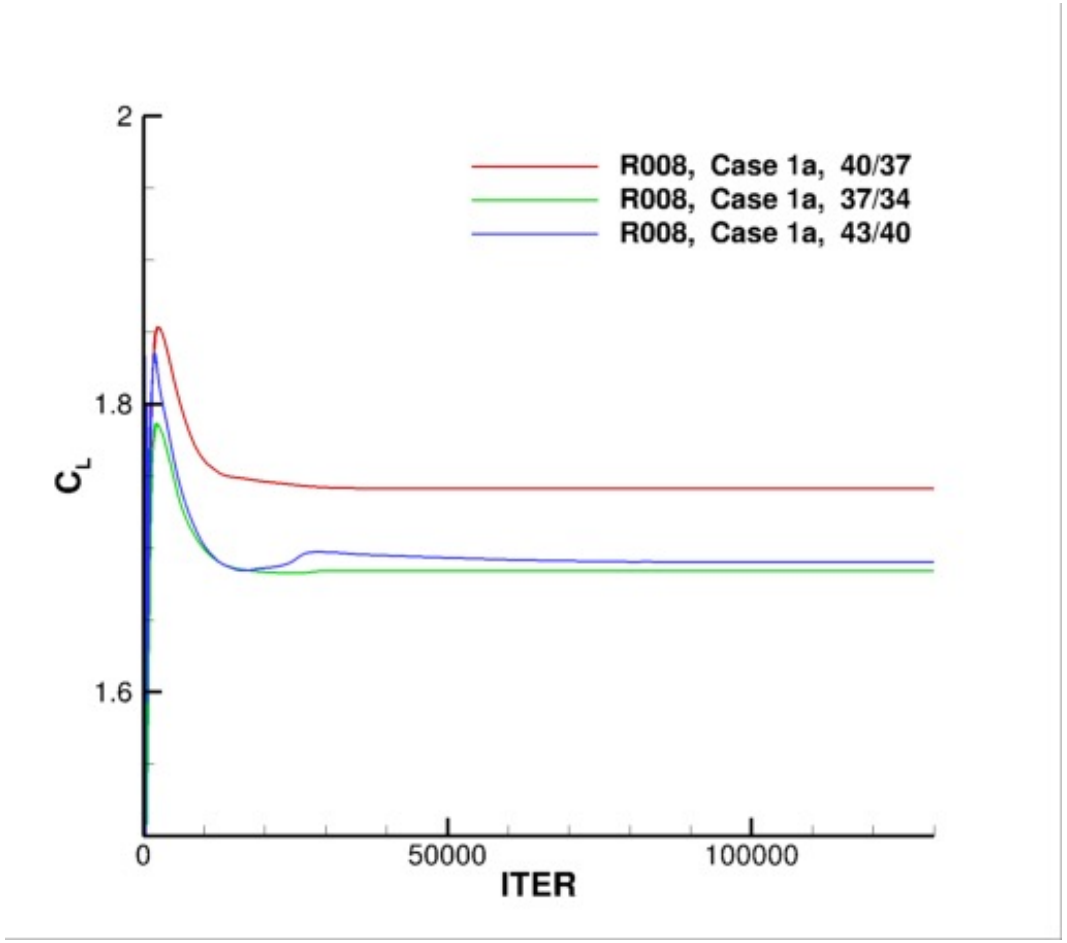
Key Findings / Lessons Learned

- Force/moment convergence attainable without residual convergence
- Many participants did not submit residual convergence data
- Available data showed a general trend of underconvergence of the solution residual

With a lack of deeply converged solutions, this Key Question is not completely answered at this time

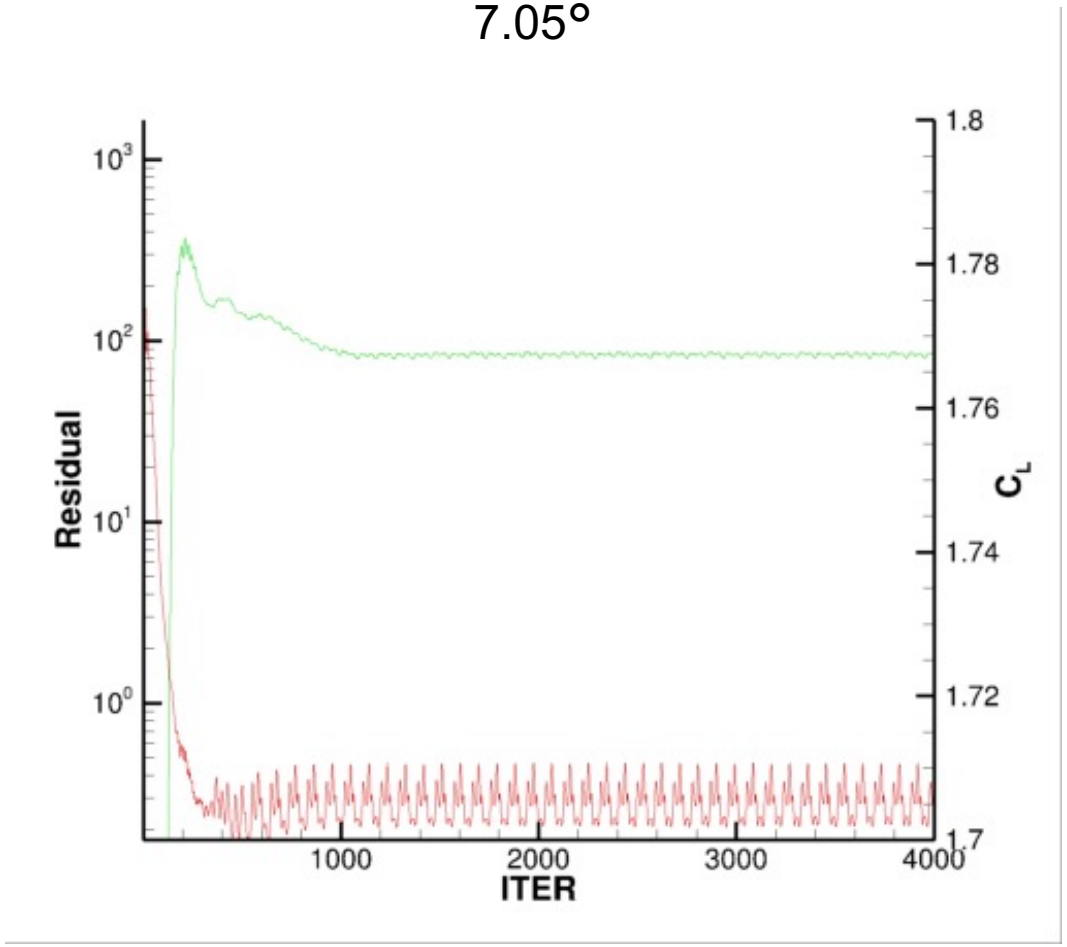
KQ4 / Case 1a: Force and Residual Convergence



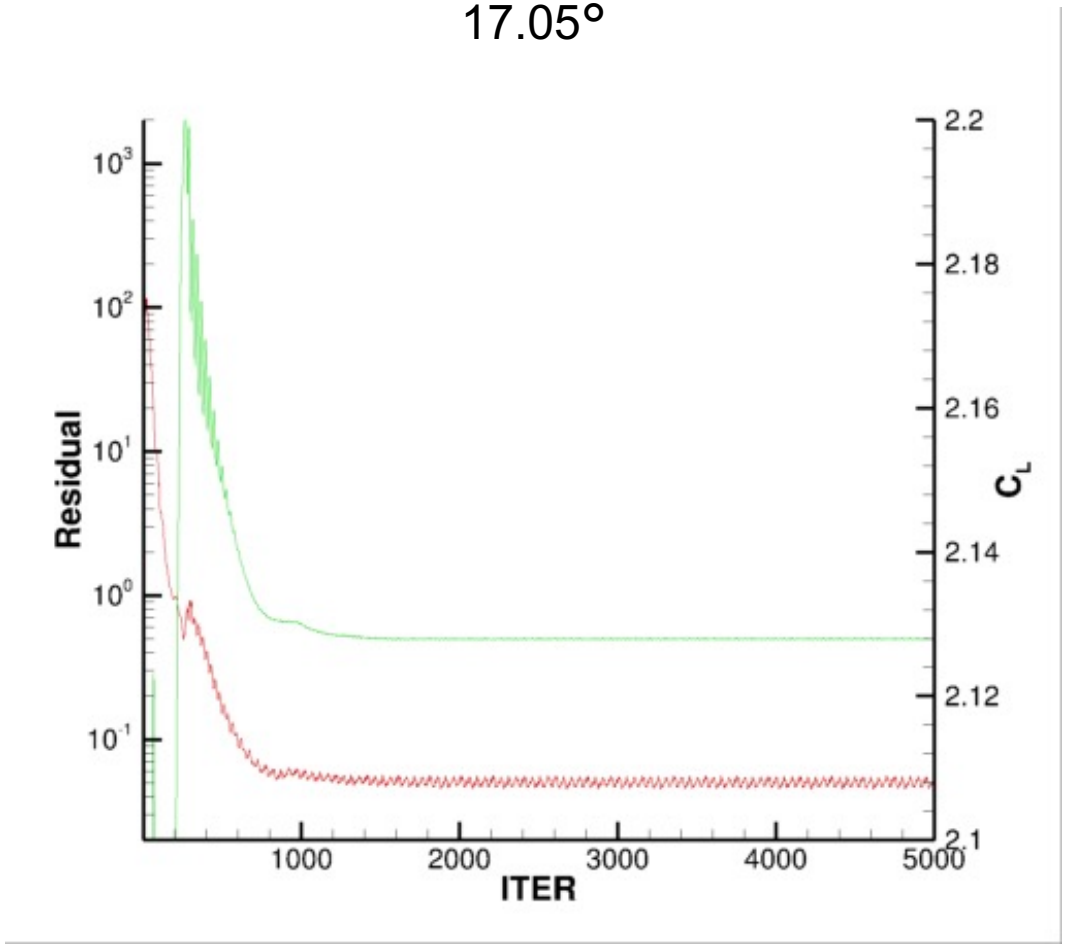


KQ4 / Case 2a: Force and Residual Convergence

7.05°

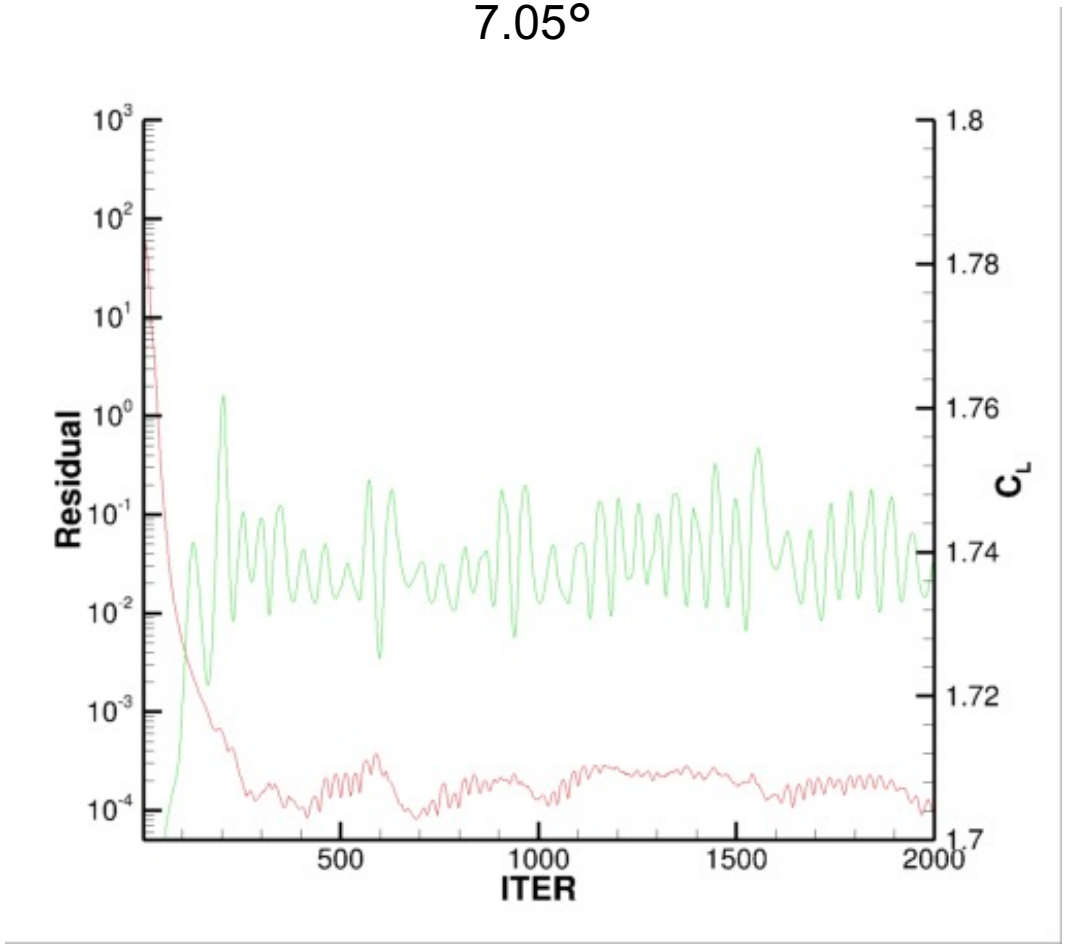


17.05°



KQ4 / Case 2a: Force and Residual Convergence

7.05°



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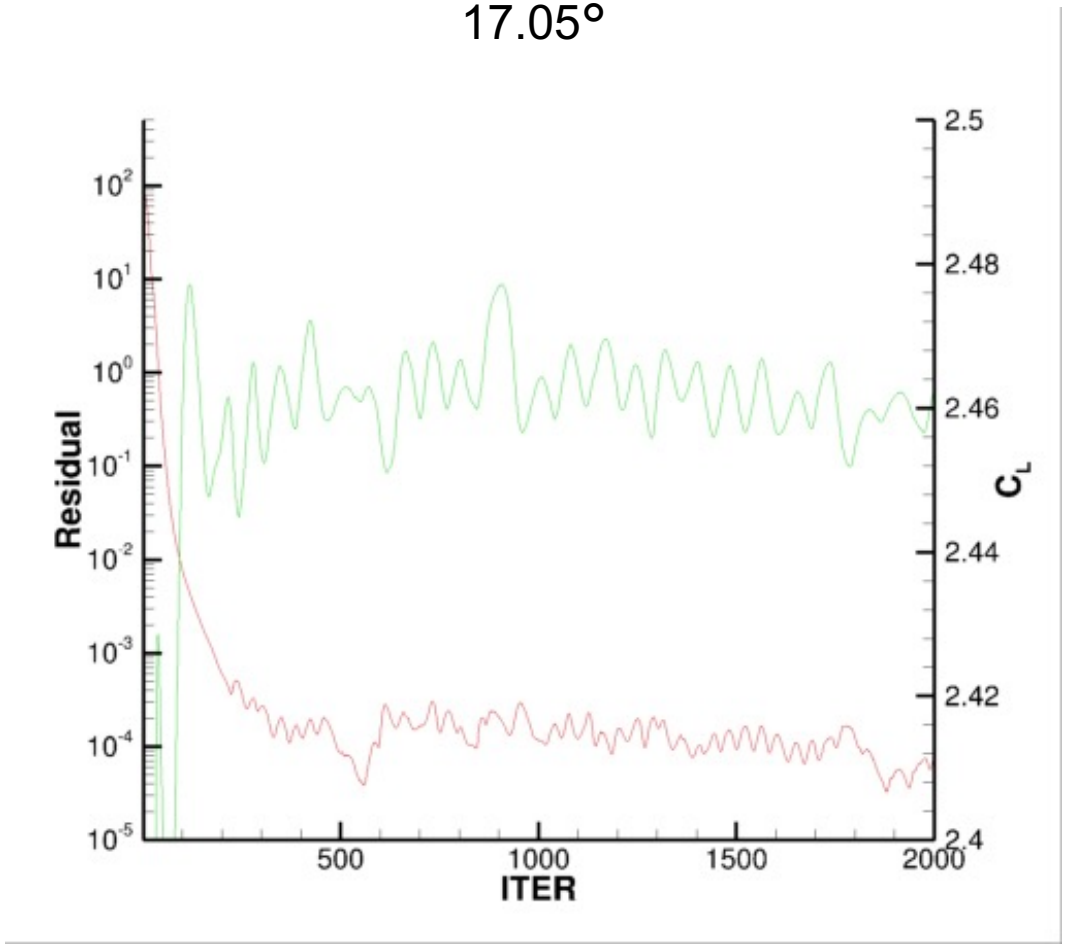
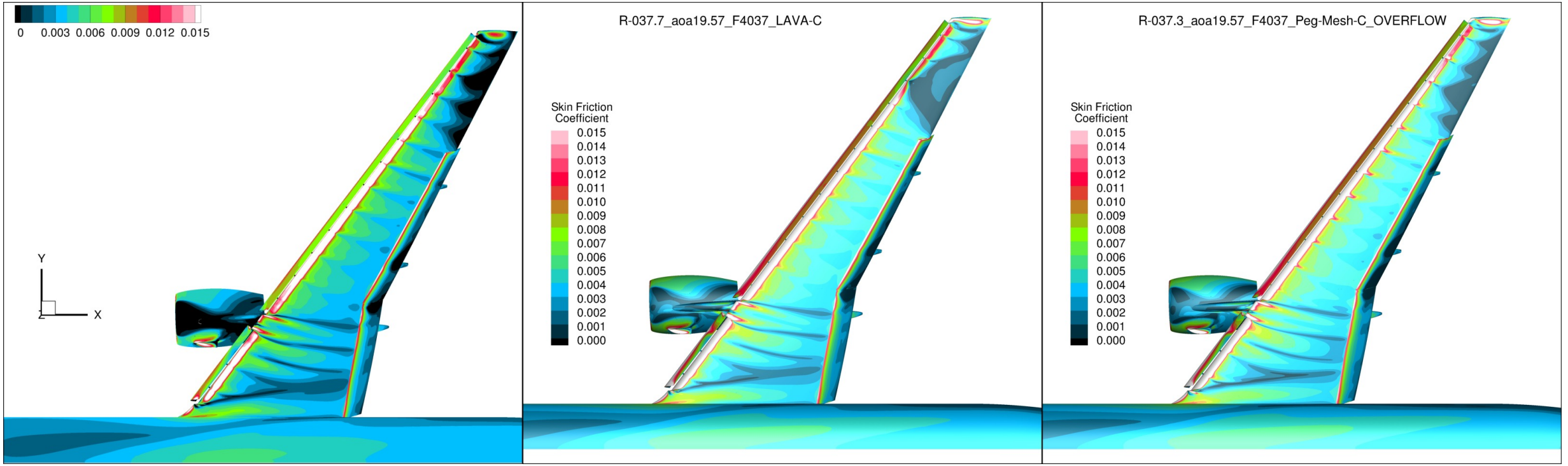


KQ4 / Case 2a: Underconvergence?

R025
LAVA / LAVA

R037
OVERFLOW / LAVA

R037
OVERFLOW / Peg5



19.57°

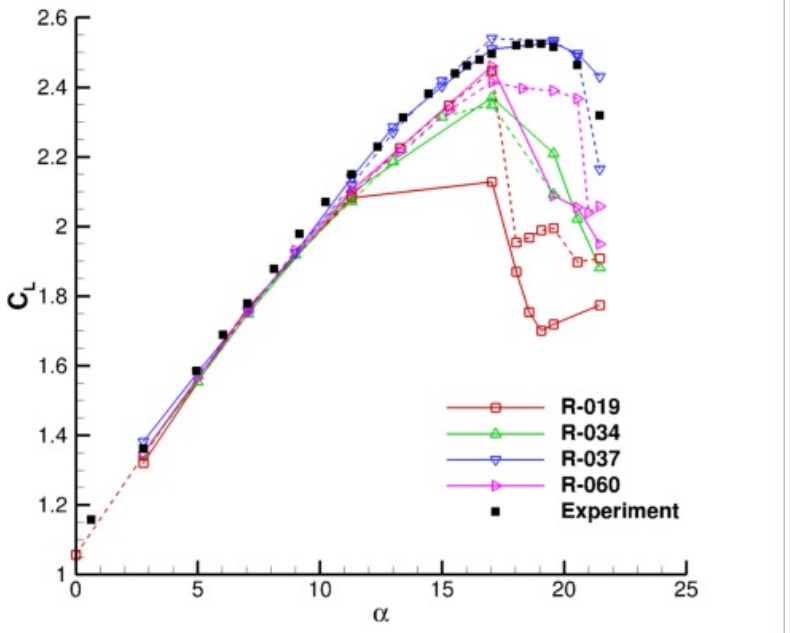
Key Findings / Lessons Learned

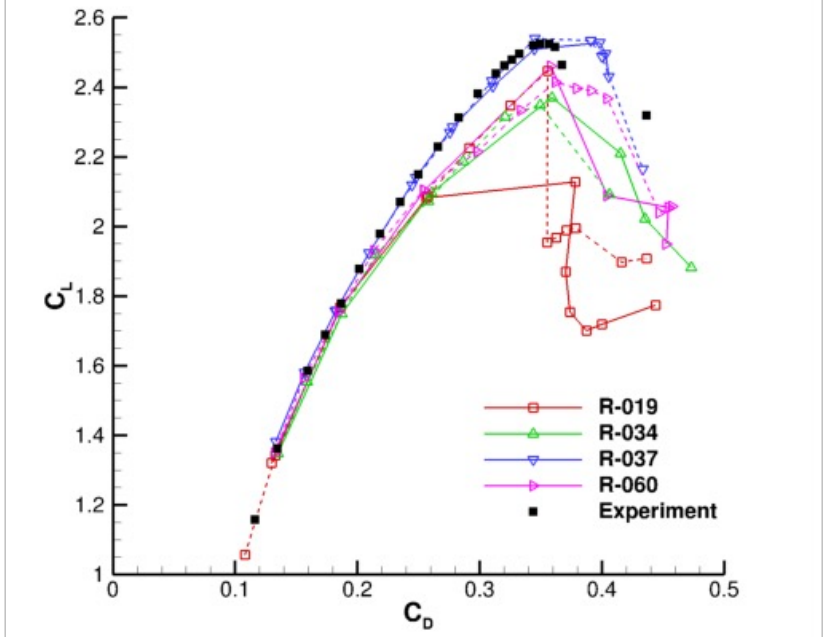
KQ 5	What is the effect of solution strategy on the predictions?

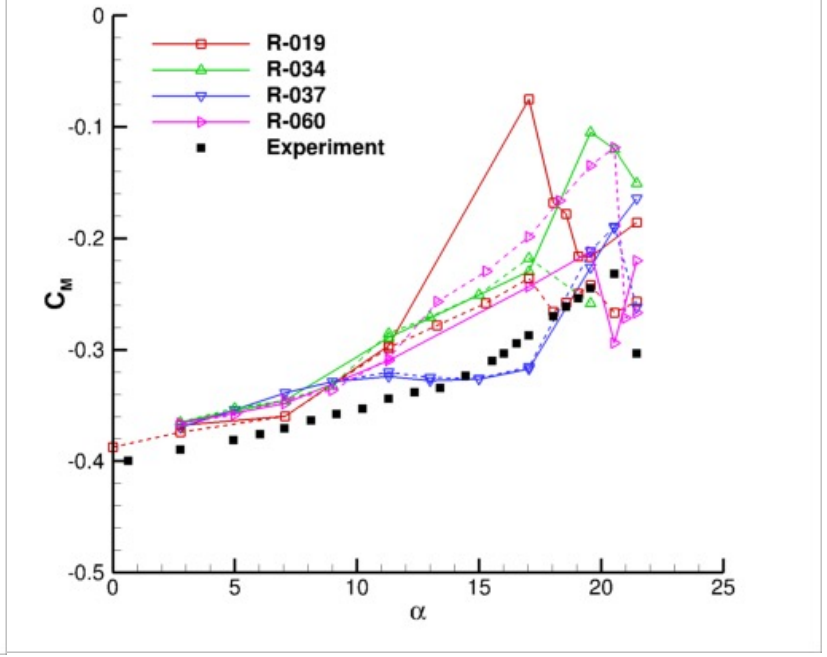
Key Findings / Lessons Learned

- Strong dependency on the code being used, but evidence that solution strategy influences the size and location of separated flow
- Little influence observed from cold versus warm starts in terms of seeing low-lift or high-lift branches, but different flow topologies were observed
- Impact of time accuracy inconclusive due to insufficient participant data; however, it was not shown to be detrimental
- Hysteresis effects were observed, but nothing conclusive. It may depend on whether or not a pitch break is predicted.
- Influence of solution strategy likely interconnected with residual underconvergence

KQ5 / Case 2a: Cold vs. Warm Starts

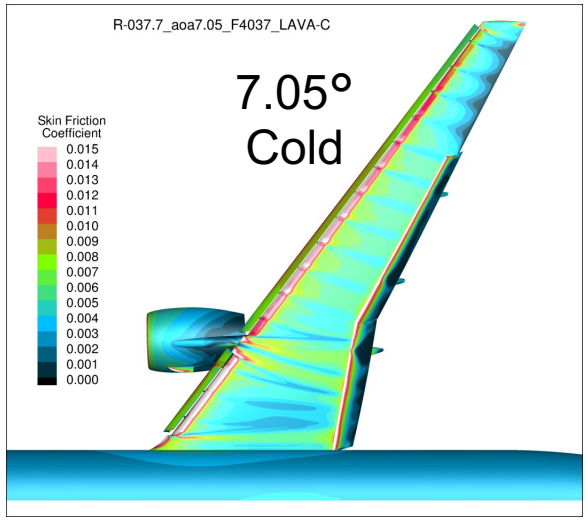


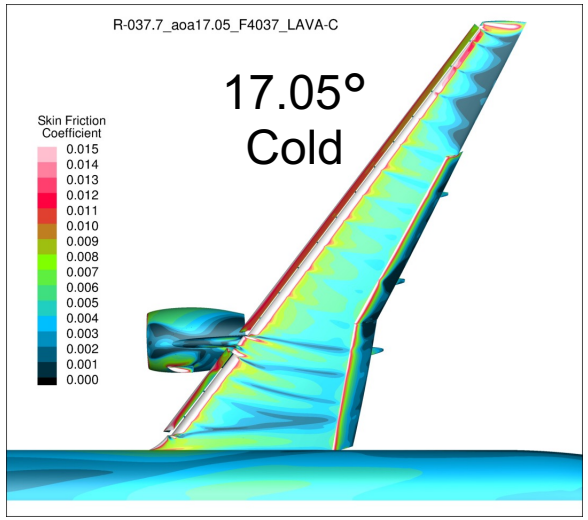


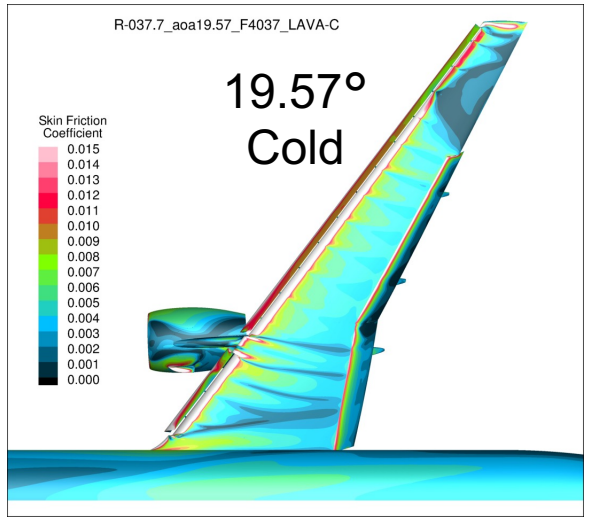


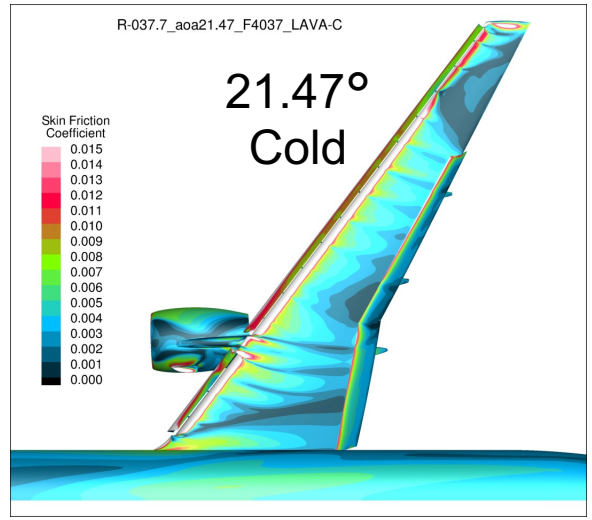
KQ5 / Case 2a: Cold vs. Warm Starts

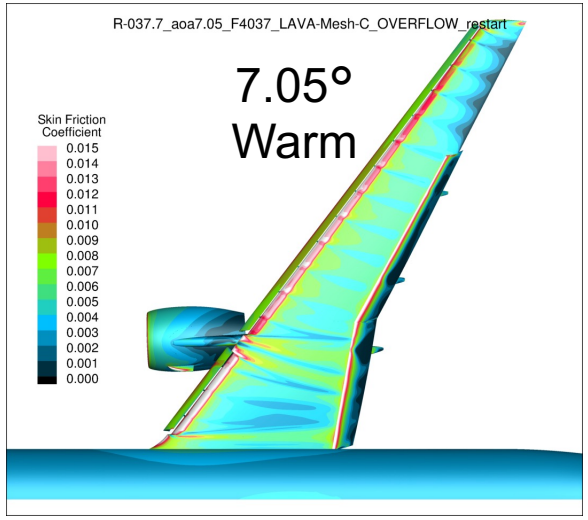
R037.7

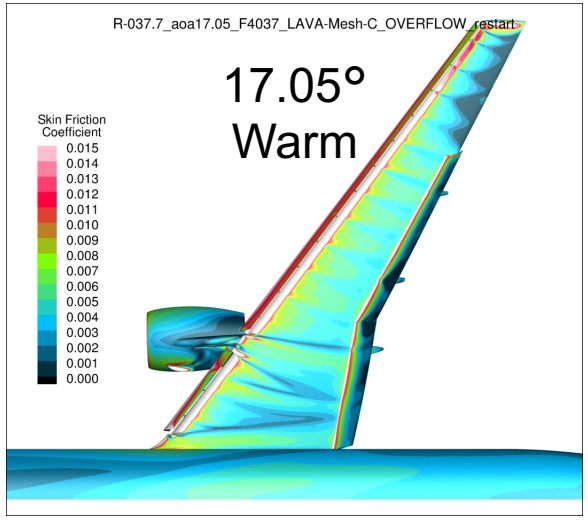


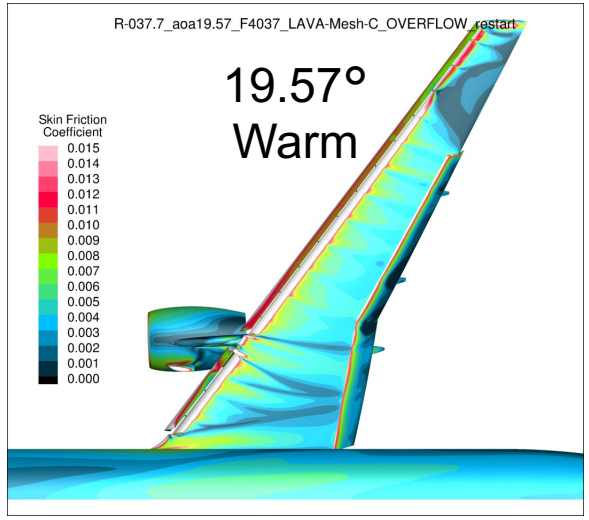


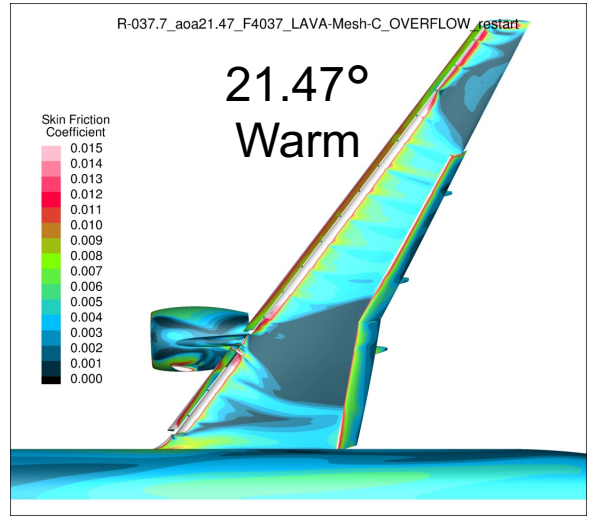






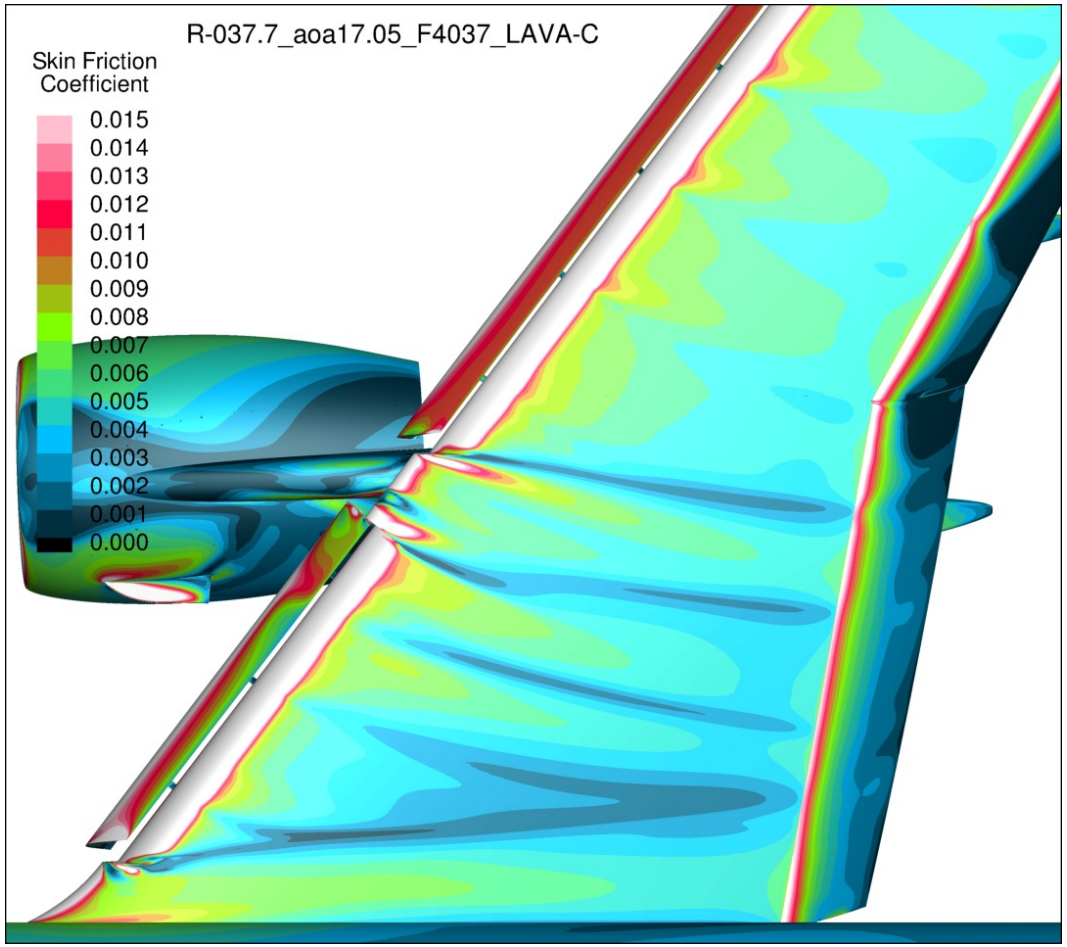


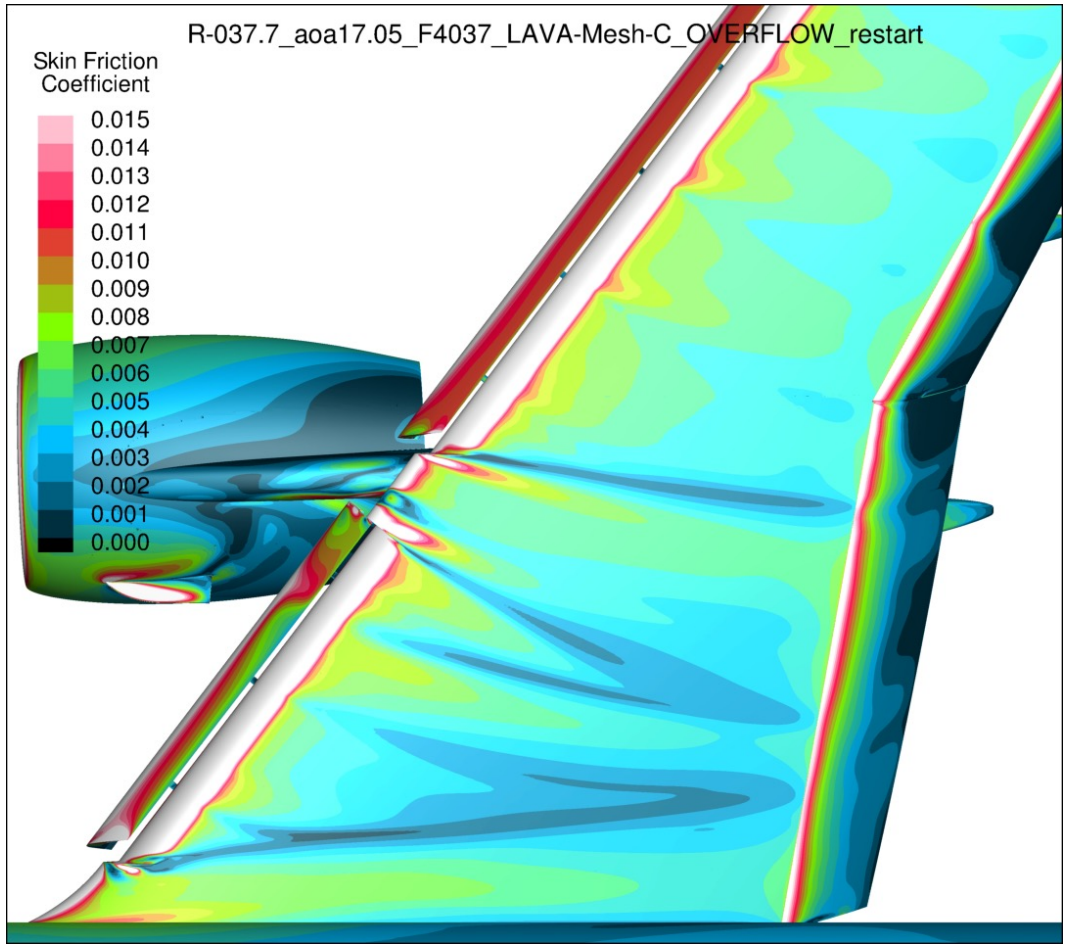




KQ5 / Case 2a: Cold vs. Warm Starts

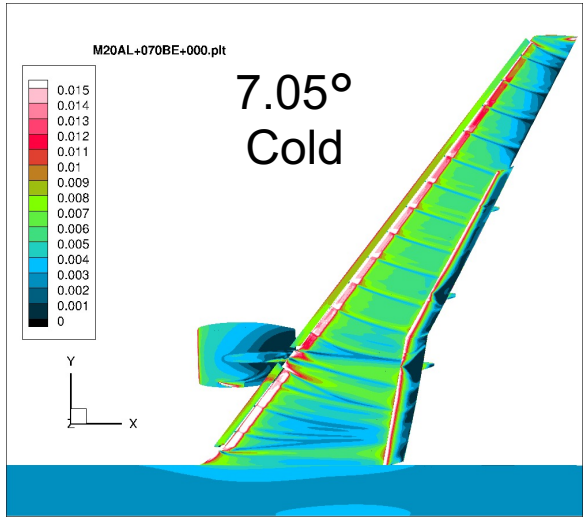
R037.7

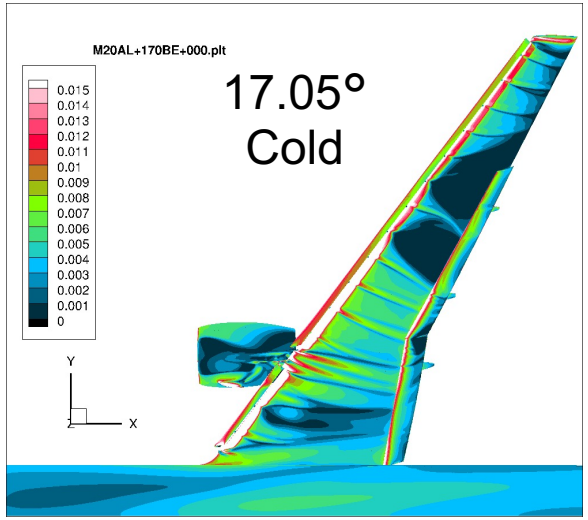


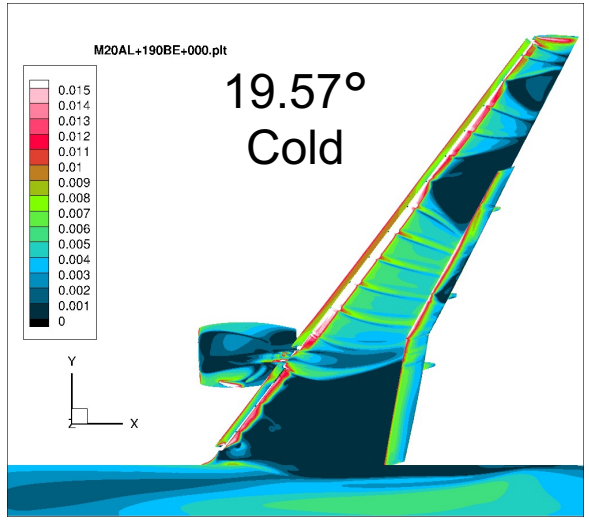


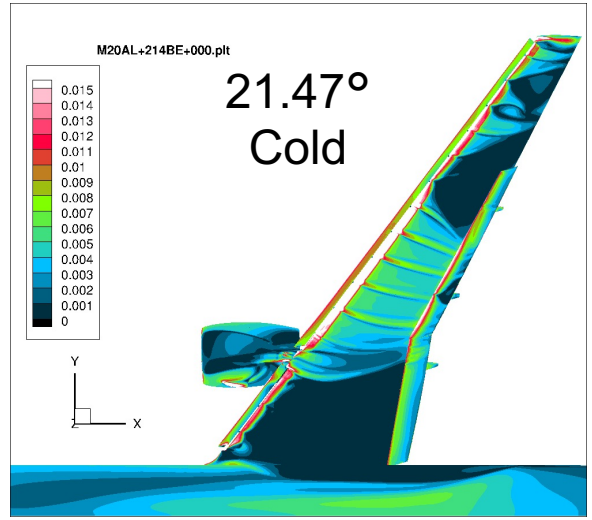
KQ5 / Case 2a: Cold vs. Warm Starts

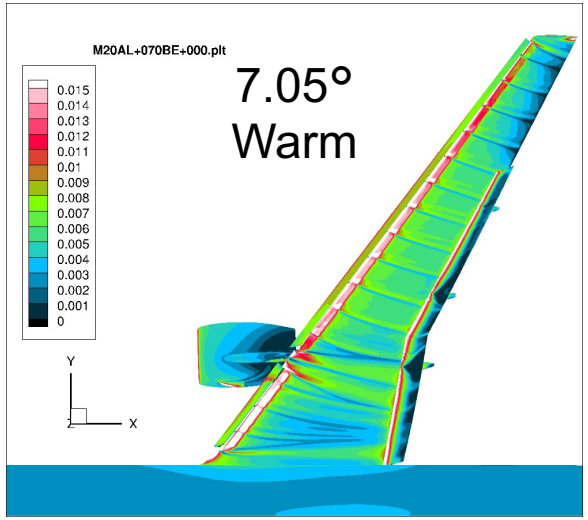
R019

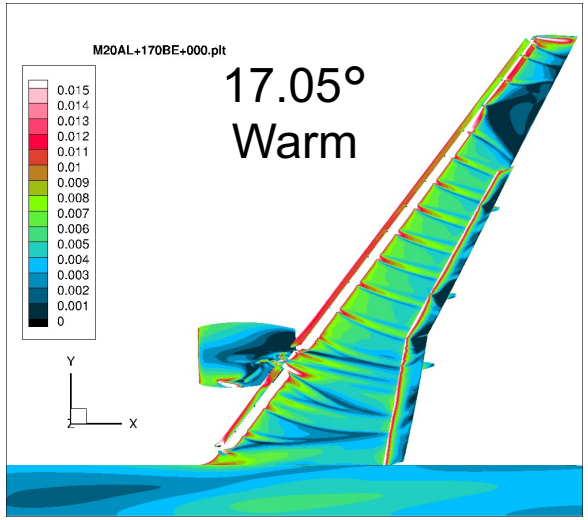


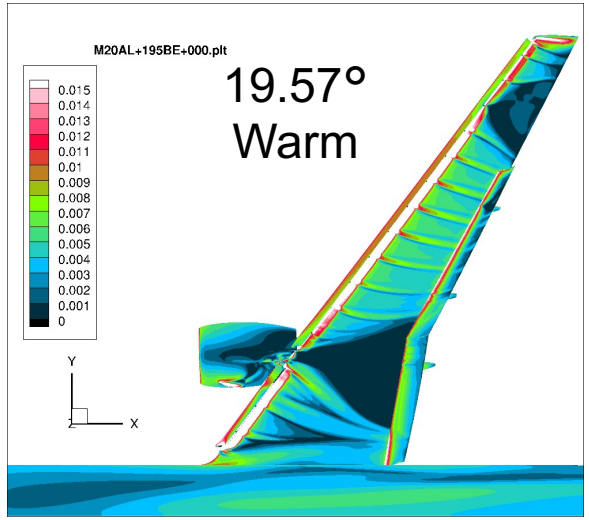


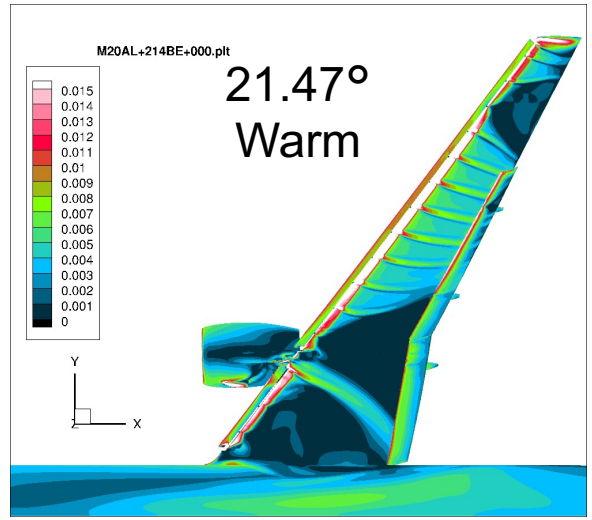




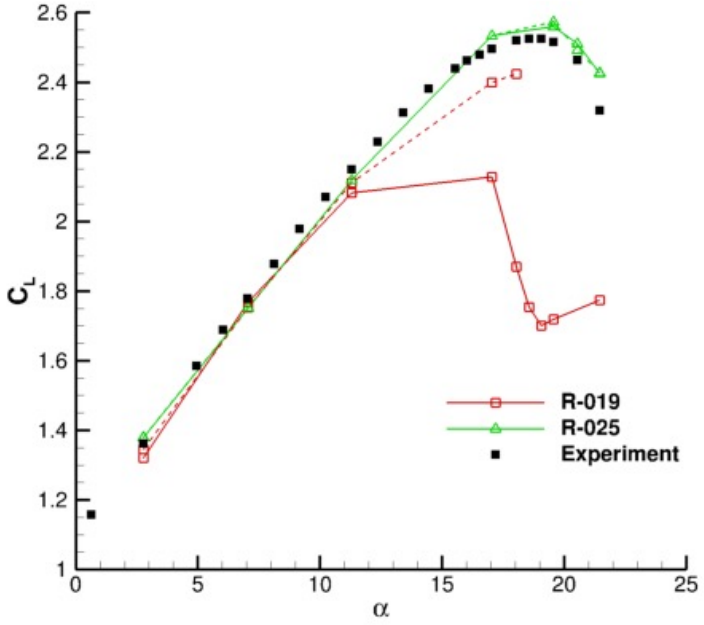


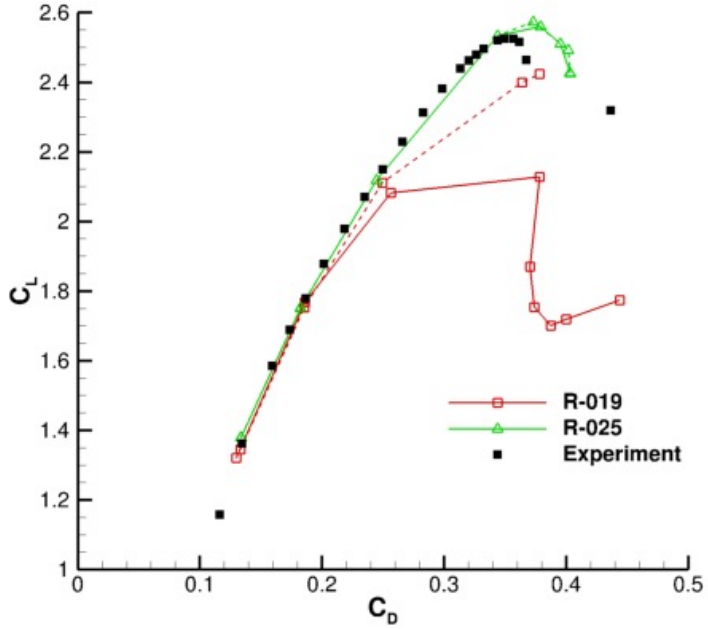


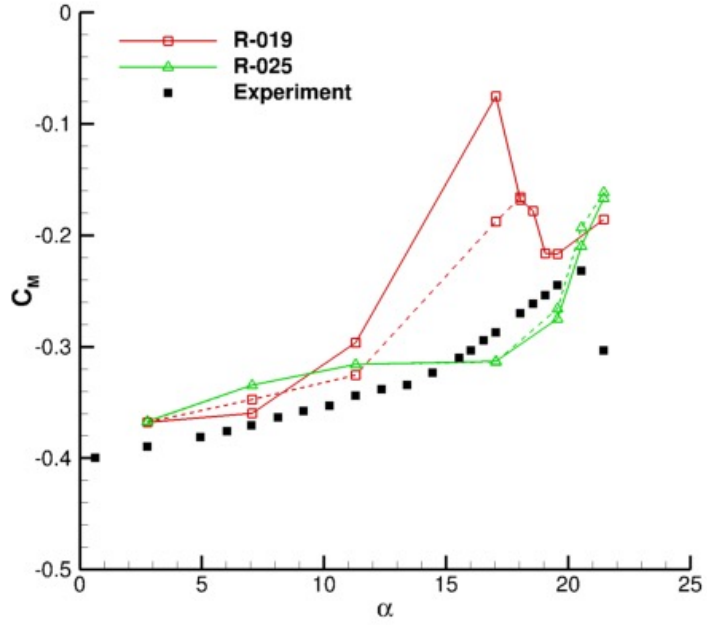




KQ5 / Case 2a: Time Accuracy

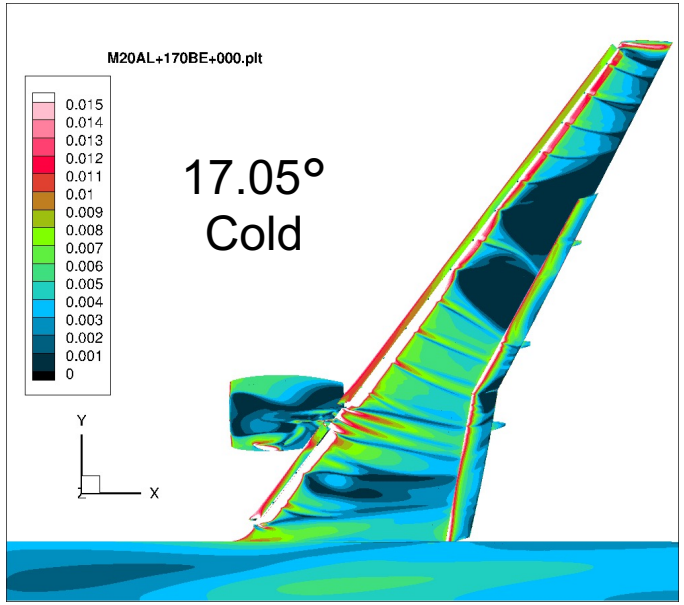


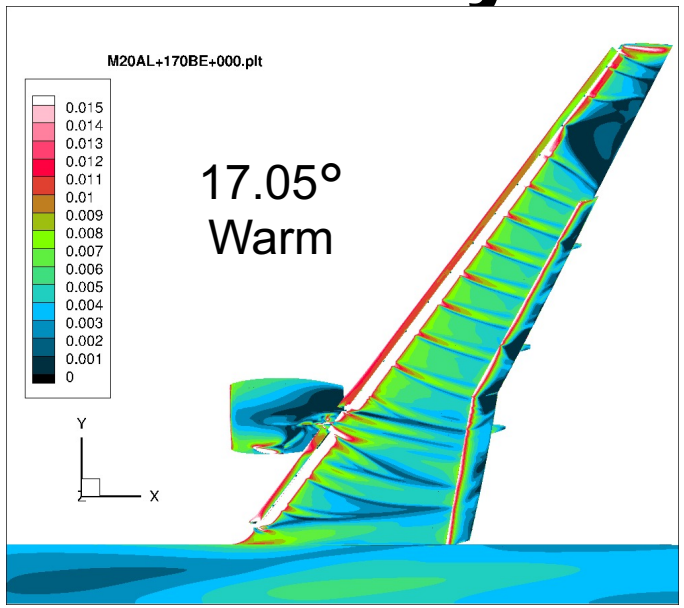


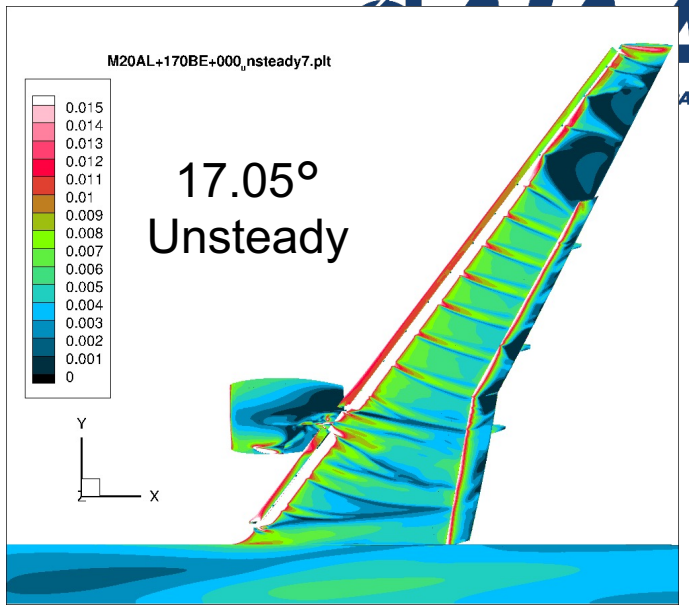


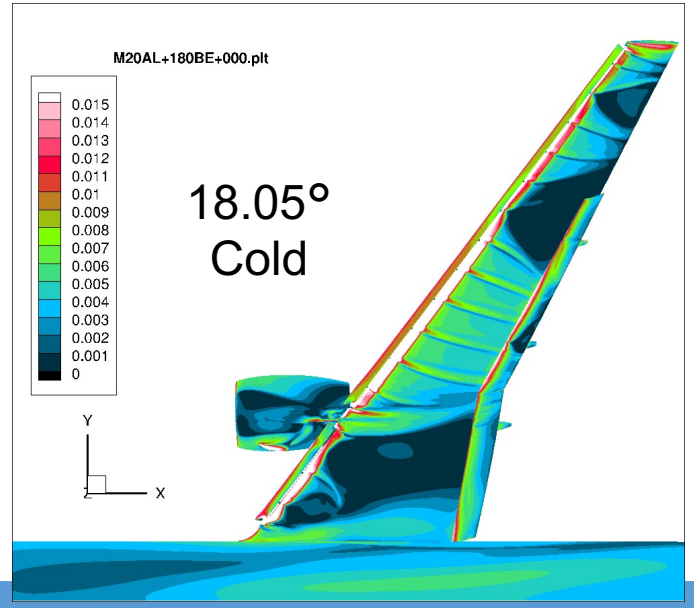
KQ5 / Case 2a: Time Accuracy

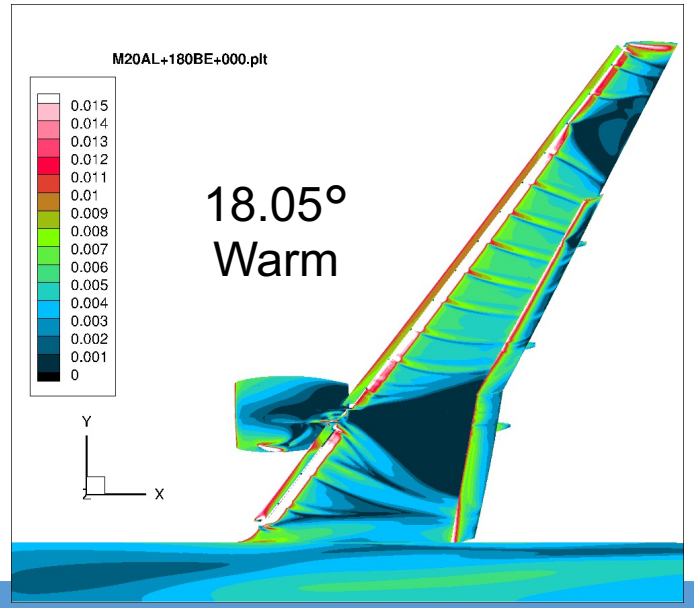
R019

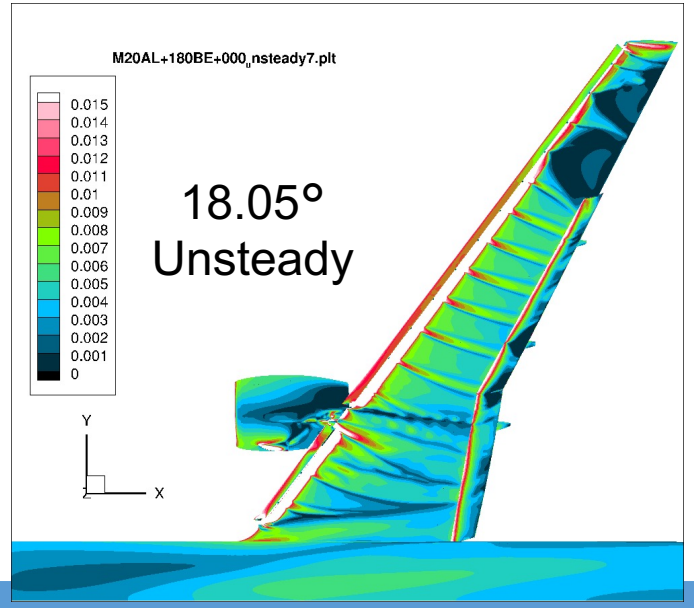






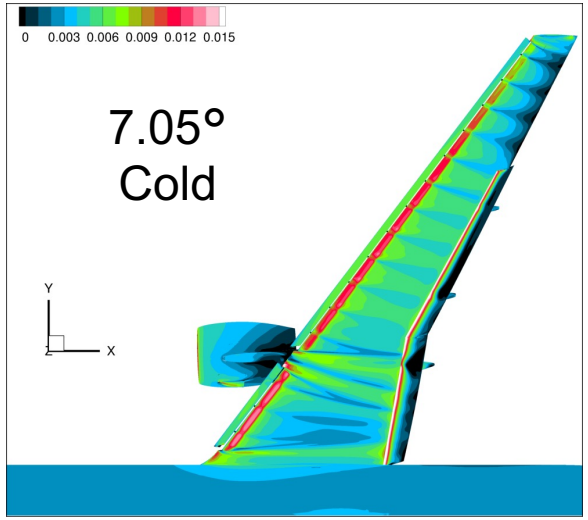


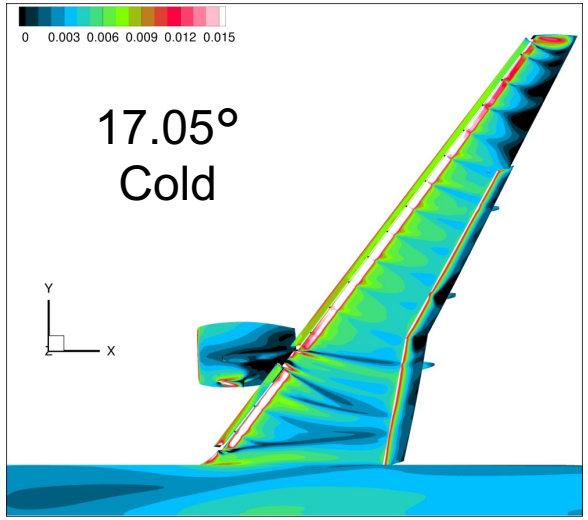


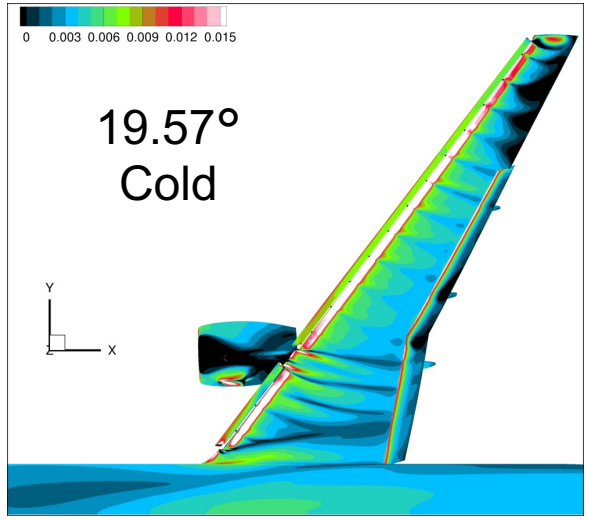


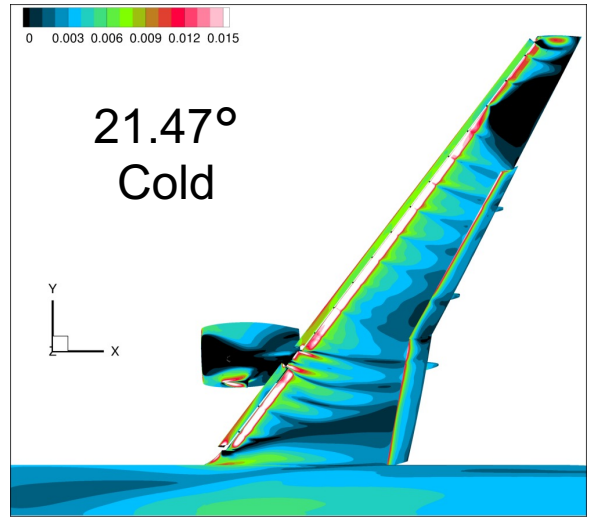
KQ5 / Case 2a: Time Accuracy

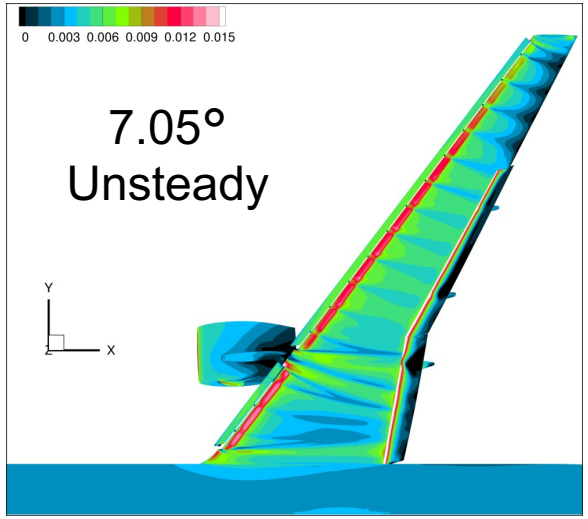
R025

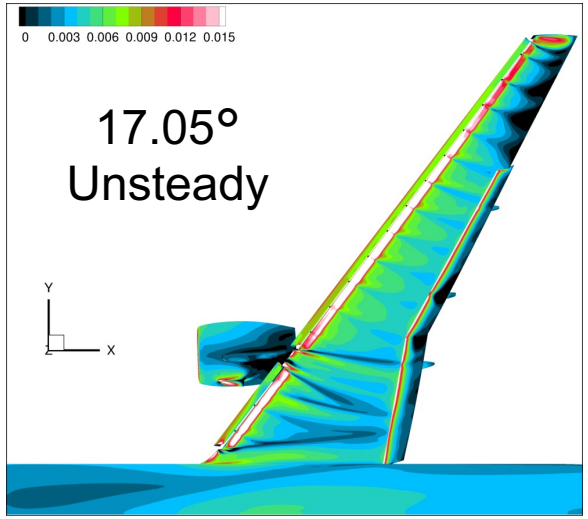


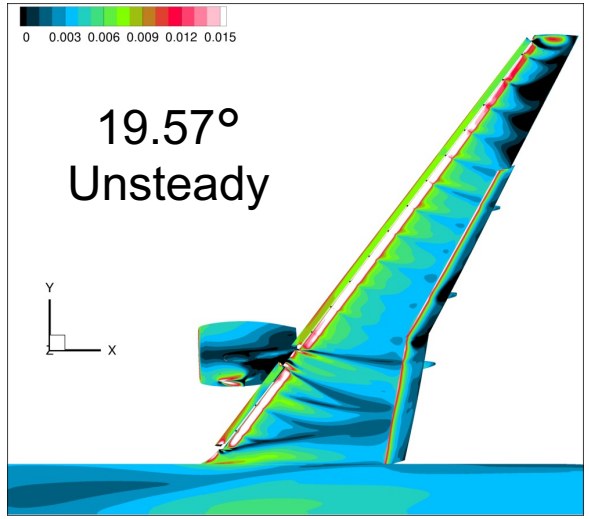


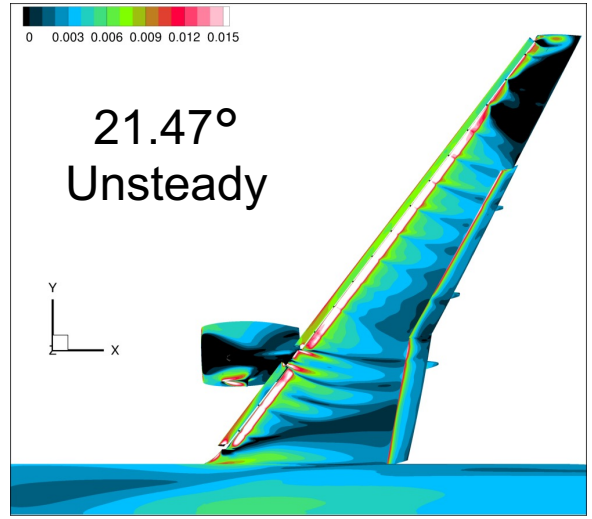




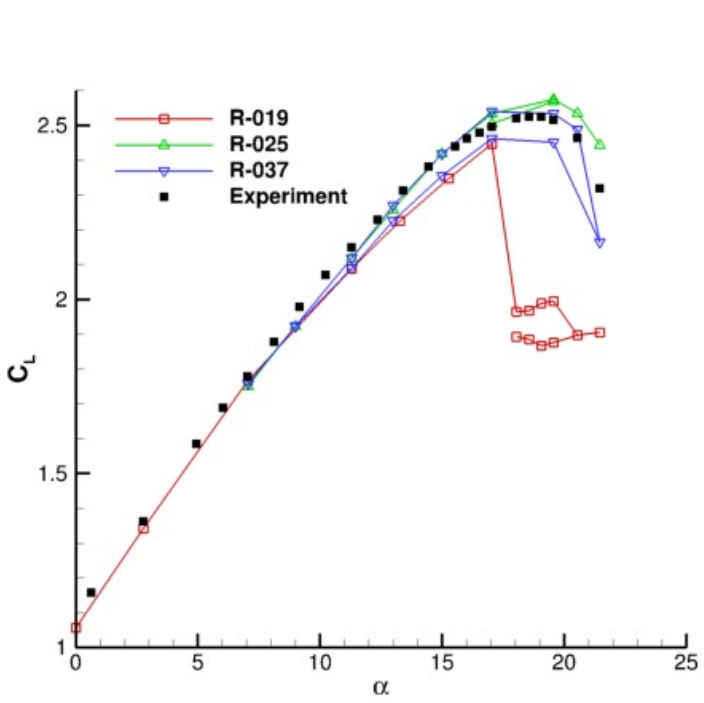


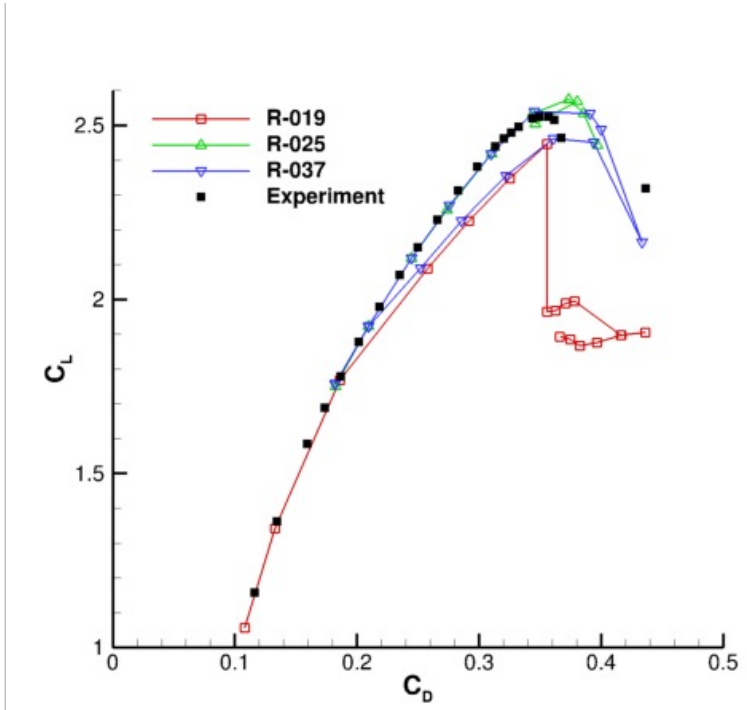


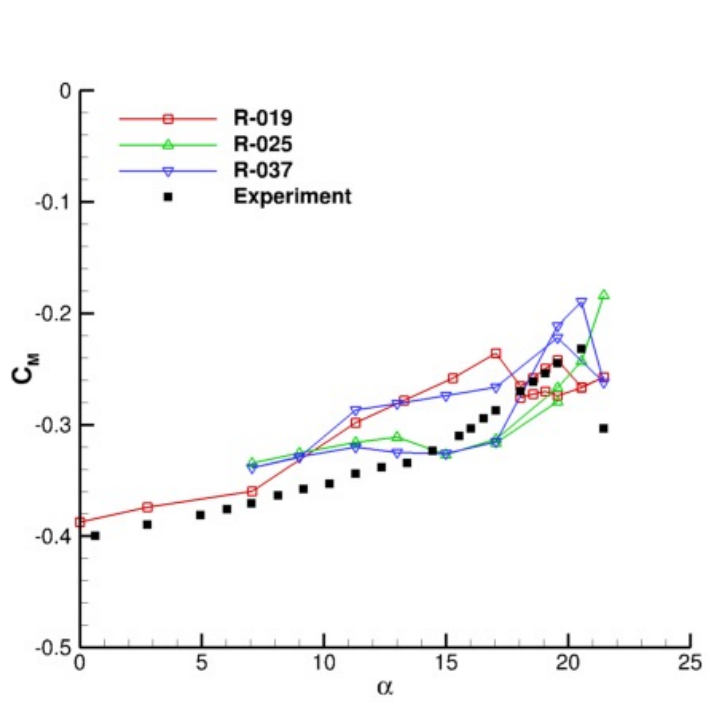




KQ5 / Case 2a: Hysteresis







Future Plans

- Professors Ollivier-Gooch and Coder have determined that no participant fully earned an ‘A’ for their Fixed-Grid RANS calculations

- We have not successfully reduced the spread of results seen in previous HLPWs
  - Participants do not obtain the same grid-converged solution on the same mesh with the same turbulence model
  - 2D Verification is still not strongly demonstrated
  - I find your lack of ~~faith~~ residual convergence disturbing

- Irrespective of the validity of the steady RANS equations for high-lift, how do we reduce the spread in participant data?